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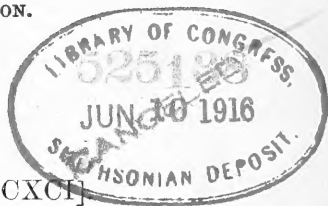
FOURTH SERIES

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THE

AMERICAN JOURNAL OF SCIENCE

[FOURTH SERIES.]

ART. I.—*A Geologic Reconnaissance of the Cuzco Valley, Peru*; by HERBERT E. GREGORY.¹ With Plates I and II.

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¹Geologist, Peruvian Expedition of 1912, under the auspices of Yale University and the National Geographic Society.

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INTRODUCTION.

Scope of the paper.—A journey from Mollendo to Lake Titicaca, continued over La Raya Pass and along Urubamba River, is sufficient to indicate the wide range of problems awaiting solution in southern Peru. The Cuzco Valley, in particular, appeals to the imagination of the scientific man. In several respects it is an unworked field. Its unusually rich archeologic material has been inadequately discussed. A study of its present and ancient inhabitants with reference to physical environment has not been undertaken; and its interesting geologic features have received but incidental mention.² The Cuzco Valley is a key area for the interpretation of the history, geography, and geology of the central Andes; it fairly bristles with scientific problems.

It was the writer's good fortune to spend the months of September, October, and November, 1912, in southern Peru. Seven weeks were devoted to geologic field work in the region adjoining Cuzco. The particular object of the expedition was a study of the gravel deposits from which human remains

² The pamphlet prepared by Dueñas (*Aspecto minero del Departamento del Cuzco*, Cuorp. Ing. de Min. del Peru, Bol. 54, Lima, 1907) marks the beginning of modern geologic studies in the Department of Cuzco. The bulletin contains valuable economic and petrographic material.

assigned to the glacial epoch have been reported.³ Time was available, however, for a geologic reconnaissance including certain detailed examinations of the western portion of the Cuzco Valley, and the results of these observations are recorded on the following pages. The geology is very complex, and the time at my disposal was insufficient for the collection of the data necessary for the solution of the many problems which arose. A much larger amount of detailed work is required before the geologic history of this interesting area can be written. The present paper is therefore a contribution to the geology of the Cuzco Valley, not a final report.

Note on the topographic map.—The base map accompanying this report (Plate I) is the first published sheet of a series covering the field of operations of the Peruvian expeditions of 1911, 1912, 1914, and 1915, conducted under the joint auspices of Yale University and the National Geographic Society. An effort has been made to produce maps of a high degree of excellence, and credit is due to the chief topographer, Mr. Albert H. Bumstead and his assistant, Mr. Osgood Hardy, for the success attained in devising field methods for use in this difficult area.

The parallels and meridians of the Cuzco Valley map are based on latitude and longitude established for the Cuzco railroad station in 1914 by Mr. Bumstead, who describes his method as follows:

"Latitude observations were made at 8 located points of a system of triangulation beginning near Cuzco and extending about 60 miles westerly and after reducing each to the Cuzco depot their mean was adopted as the latitude of that point. The instrument used was a small Berger transit reading direct to 30" and by estimation to 10". In all 233 observations were made; 177 being meridian altitudes of stars, 32 exmeridian altitudes of stars and 24 exmeridian altitudes of the sun. The probable error in the latitudes of the several stations ranged from 1" to 9" with a mean of 4"."

All the latitude stations were on the highland between the great canyons of the Urubamba and Apurimac rivers which flow approximately parallel from east to west, and about

³ Gregory, Herbert E., The gravels at Cuzco, Peru; this Journal, xxxvi, pp. 15-29, 1913. In this paper the topography, structure, history, and age of the enormous gravel fan on the edge of which the city of Cuzco is built are discussed in detail, and they will not be further treated in the present report.

30 miles apart. As would naturally be expected, there was a decided disagreement between the latitudes as observed and the latitudes as computed by triangulation, starting from any given place, due to local deflections of the plumb line. The effect was to shorten the radii of curvatures of the meridians crossing this upland and to make all latitudes observed near its southern margin come out too far south and all near the northern margin too far north. Owing to the extremely irregular character of the surface these plumb line deflections can be only roughly estimated, so that it is to be expected that when the Cuzco Valley map is connected to a more extended system of triangulation, an error possibly as great as 4 or 5 seconds may be found in the latitude. Mr. Bumstead reports:

"The greatest differences between plumb line deflections were found between two stations north and south of the great peak of Salcantay which rises more than 15,000 feet above the canyons on either side. There the difference of latitude by triangulation is $15^{\circ} 37''.1$ and by observations $16^{\circ} 13''.5$, a difference of $36''.4$, only a small part of which can possibly be accounted for by uncertainties in the observations."

The astronomical latitude of the Cuzco depot as found from meridian altitudes of 66 stars is— $13^{\circ} 31' 29'' 1''.4$, and the geodetic latitude adopted as described by Mr. Bumstead is— $13^{\circ} 31' 33''.5$.

In 1914 the Peruvian Government and the Harvard Observatory coöperated with the field party in a series of wireless time signals. At about 7 o'clock each night 30 signals were sent out from the powerful station at San Cristobal at intervals of about ten seconds. These were received in the field and at the Observatory at Arequipa, where the exact times at which the signals were sent were noted by the Observatory clock, corrected by frequent observations of stars. Thus by a subsequent comparison of notes the error of the field chronometer was deduced. The success of this method of comparison is shown by an average error probably of only $\pm^s 0.03$.

Immediately after comparing the chronometer, local time was observed by altitudes of east and west stars taken with the transit previously described.

The following table from Mr. Bumstead's report shows the four values from which the longitude of the Cuzco depot was derived:

Longitude Station Number.	Probable error of comparison of field chronometer. Seconds.	Probable error in local time. Seconds.	Longitude reduced by triangulation to Cuzco depot.	Weight (inversely proportional to probable error in local time).
57	±0.02	±0.11	71° 58' 38" .9	1.
46	±0.04	±0.16	42 .8	0.7
363	±0.02	±0.11	41 .6	1.
636	±0.03	±0.19	54 .7	0.6
Weighted mean			71° 58' 43" .4	

It is probable that these results are affected by local deviations of the plumb line, but not so much as the latitude, for the trend of the mountain ranges is east and west.

Azimuths determined by solar compass in 1912 were checked by more precise methods in 1914.

The altitudes of the topographic map are based on the height of the rails at Cuzco station, as determined by Mr. T. A. Corry. As a basis for plane-table triangulation a base line 2 miles in length was measured along the railroad, and angles from its ends were measured to points on the rim of the valley. Two of these points, 6.4 miles apart, were used as bases for the whole map.

Owing to conditions incident to exploration, the quality of the map is not uniform. The area marked C on the accompanying sketch (fig. 1) was surveyed by Mr. Robert Stephenson. This portion of the Cuzco Valley is intricately dissected, and the time at the disposal of the topographer was brief. The features are therefore somewhat generalized. The area marked A is covered by a plane-table survey made by Mr. Bumstead, who describes his method as follows:

"I went over the ground very thoroughly, making many stations by the three point method and locating almost all the features by intersection. The fact that the ground is entirely unobscured by trees made this the ideal method, and levels were always obtainable by vertical angles to some point or points whose elevation had been previously determined.

In a country of so great differences of elevation, the use of steep vertical angles for topography is unavoidable, and unless distances are known more accurately than they can be scaled on a map of so small a scale, resulting determinations of eleva-

tions are subject to considerable error. To reduce this error as much as possible, and to prevent the accumulation of errors of elevation, I ran a line of levels down the railroad from Cuzco to the ends of the base line and then with vertical angles and the computed distances of the transit triangulation found the elevations of Ccorao and Picol, on the north side of the valley, and Huanacapria, on the south side. Then, in making plane-table stations I was able to get a fairly flat vertical angle to

FIG. 1.

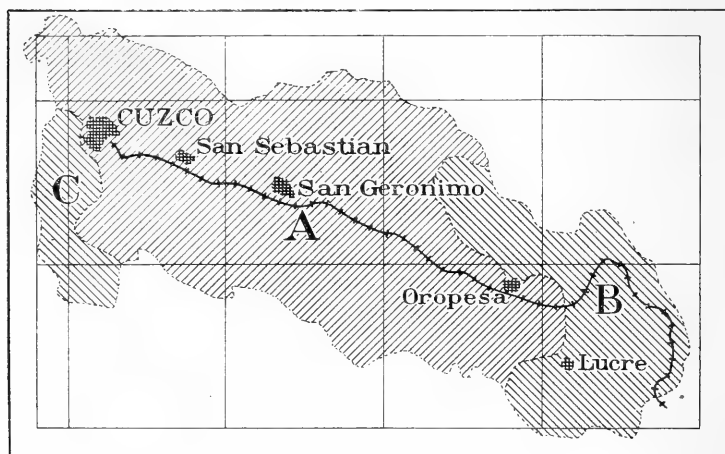


FIG. 1. Areas surveyed by members of the Peruvian Expedition of 1912,—A, A. H. Bumstead; B, A. H. Bumstead and Robert Stephenson; C, Robert Stephenson. Cities mapped by J. P. Little. Osgood Hardy acted as Mr. Bumstead's assistant throughout.

some one of these points, or to points of known elevation along the railroad. I soon had a considerable number of points scattered about the sheet, whose elevations were well determined and checked, and from these I always worked."

The area marked B is mapped from a reconnaissance survey by Mr. Bumstead and Mr. Stephenson, following the methods adopted for area A. The streets of Cuzco, San Sebastian and San Geronimo were surveyed by Mr. J. P. Little, topographic assistant; the plats of Oropesa, Lucre, and other villages are generalized. Time did not permit the tracing of trails, and therefore many important ones are not shown.

For the spelling of geographic names, the expedition is indebted to the Centro Geográfico del Cuzco, and its President, Dr. A. A. Giesecke, Rector of the Cugo University.

Note on the geologic map.—The geologic map of the Cuzco Valley (Plate II) represents the results of reconnaissance, not detailed work. At the time the geologic work was done only an incomplete print of the central portion of the topographic map was available, and it has not been possible to avoid errors in transferring to the completed map observations obtained by compass traverse. No boundaries of formations have been traced throughout their extent; and the directions of fault traces are only approximately known. The altitude of the strata is indicated by dip and strike symbols; but it has not seemed wise to record my incomplete observations regarding trends of the intricately interlocking synclines and anticlines or to undertake at this time a systematic discussion of local and regional structure.

Though obviously subject to radical revision, the map represents substantially the present state of knowledge regarding the geology of the Cuzco Valley, and I trust it will be found helpful to those who undertake detailed work in the little cultivated but fertile field of Peruvian geology.

I. TOPOGRAPHY.

Topographic setting.—The geographic position of the Cuzco Valley is shown in fig. 2. Though possessing unusual scientific interest, it is relatively a minor topographic feature. Viewed broadly it is one of many small valleys tributary to a group of canyons whose waters supply the Amazon. A surface profile of southern Peru drawn through Cuzco reveals the presence of an extensive area of upland sharply bounded on the southwest by the Peruvian coastal plain and on the northeast by slopes leading to the Amazon (fig. 3). This surface, which may be called the Peruvian Plateau, is part of the Andean Plateau—one of the greatest of the world's highlands. Above this plateau surface, which stands at 13,000 to 15,000 feet above the sea, rise snow-clad peaks—volcanic on the Pacific side and erosion remnants on the Amazon side—and below it are sunk profound canyons. The upward and downward departures from a level at approximately 14,000 feet are about equal in amount and involve areas of about equal extent. On the southern border of Peru the upland surface is broken into a

Western Plateau and an Eastern Plateau by the sunken interior basin holding the waters of Lake Titicaca. In the latitude of Cuzco these relations are not duplicated; the Andean plateau is practically uninterrupted and the terms Eastern Cordillera

FIG. 2.

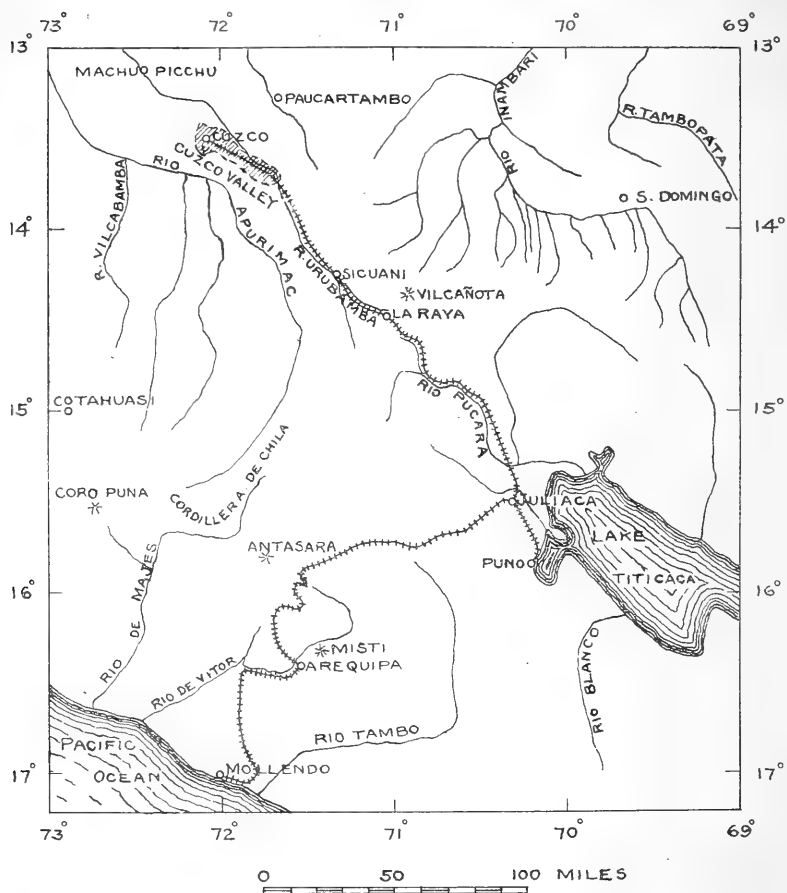


FIG. 2. Outline map of a portion of Southern Peru, showing the location of Cuzco Valley.

and Western Cordillera have little significance. The dominant topographic feature of southern Peru is a widely extended plateau, not chains of lofty mountains, as represented in standard atlases.

Relief.—The rim of the Cuzco Valley stands at an average elevation of about 13,500 feet and is surmounted by peaks

reaching upward to heights exceeding 14,500 feet. This bordering wall is breached by passes between 12,000 and 14,000 feet high, through which access is afforded to the valley floor, lying below 11,100 feet. The extremes of elevation are the summit of Cerro Pachatusca (15,915 feet) and the mouth of the Huatanay (10,100 feet).

The floor of the Cuzco Valley, 19 miles in length, is divided by the Angostura and Oropesa narrows into three oval areas of flat-lying land, displayed like links in a chain. From these valley flats thinly coated rock slopes rise with a gradient of 1,000 to 2,000 feet to the mile, in places becoming precipitous. The steeply inclined slopes continue upward from the central

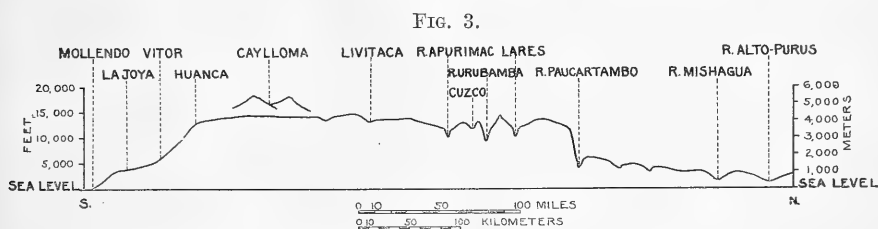


FIG. 3. Surface profile of Southern Peru, drawn across the mountainous area from the Pacific Ocean to the Amazon Plains on the 72° W. longitude.

valley until areas of slight relief (the pampas) are reached. Huaca-Cancha, Bambanusa, and Huanca-Huanca pampas spread out at elevations of 13,500 feet; Pampa de Kkallachaca and adjoining plateaus, developed on the limestone north of Cuzco, stand at about 12,000 feet—1,000 feet above the valley floor. The outer wall inclosing the Cuzco Valley is trenched in many places by streams leading away from the valley and toward the Apurimac and the Urubamba; the serrate rim of the valley therefore does not correspond to the divide between drainage basins. In general the southward facing slopes of the valley are cut by deep canyons and exhibit great local relief; the northward-facing slopes are gentler and less abrupt and in places above Angostura Narrows are traversed by flat-floored, terraced valleys.

Extrusive volcanic rocks have modified the topography of Bambanusa Pampa and have interfered with the normal development of relief at Oropesa and Rumiccolca; elsewhere the surface is elaborately dissected in response to the influence of the variable composition and complicated structure of the underlying sedimentary rocks.

The three basins.—The expanded portion of the valley floor between Cuzco and the Angostura Narrows may be termed the Cuzco Basin. It is an intensively cultivated area, the seat of Inca civilization at the time of the Spanish conquest, and the present home of over 90 per cent of the inhabitants of the Cuzco Province. The basin is bordered by gravel fans and low cliffs cut in poorly consolidated sediments. As viewed from its eastern margin the floor of the basin is flat, but near at hand it is seen to consist of two portions separated by a low rock ridge thickly mantled with sand. This ridge has little topographic importance but serves to separate two areas of tillable land and to determine the location of the villages of San Sebastian and San Geronimo. The portion of the basin floor west of this agricultural divide is almost without relief (fig. 4). As seen from Ttica-Ttica the minor inequalities on the floor of the basin disappear and a graded surface, sloping gently eastward and broken only by groves of eucalyptus and the houses of the city of Cuzco, is presented to view (fig. 5). The landscape is a garden with plats of barley and potatoes, bordered by high stone walls and traversed by irrigation ditches. In the vicinity of San Geronimo the flat floor of the Cuzco Basin is confined to a strip half a mile wide bordering the Huatanay. The village itself is set on the edge of an enormous alluvial fan built outward from the mouths of rock-walled canyons which score the slopes of Picol (fig. 6).

The topographic features of the Cuzco Basin are duplicated in several respects by the Oropesa Basin (fig. 7). The Oropesa Basin has, however, less width and a flatter floor than its larger companion. The Lucre Basin shows the least relief of the three subdivisions of the Cuzco Valley.

Drainage.—The sinuous line marking the rim of the Cuzco Valley forms a rough rectangle with a length of 22 miles and an average width of 7 miles. The 154 square miles thus inclosed is drained by a single stream, the Huatanay, which occupies an axial position from its source to the village of Huacarpay. Thence it turns sharply northward, escapes through the valley wall, and joins the Urubamba at Sierra-Bella. The Huatanay rises in flat-floored glaciated swales at the base of Cerro Sencca, where numerous springs issuing from till insure perennial flow. During the rainy season the supply obtained from ground water is supplemented by torrents which traverse deep rock grooves, cut in the mountain slopes to heights of 14,000 feet. Through the city of Cuzco the

FIG. 4.



FIG. 4. View of floor of the Cuzco Basin from Quispiquilla; San Sebastian is in the right foreground; Cuzco in the middle distance.

FIG. 5.

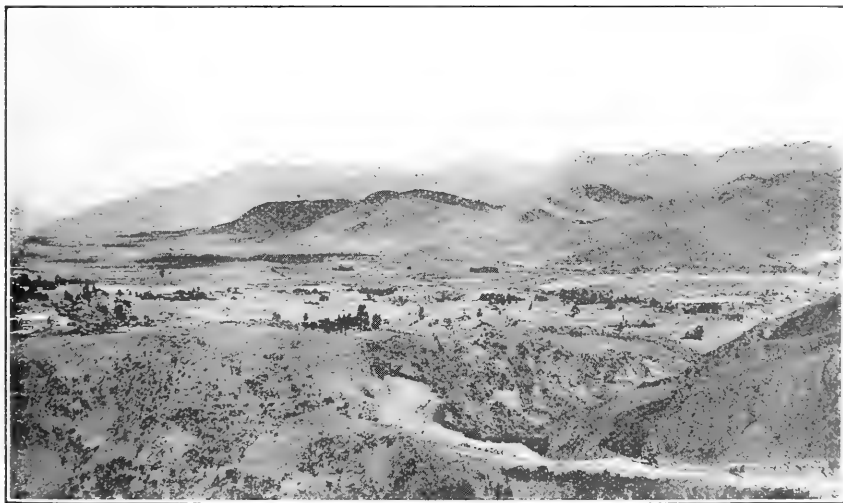


FIG. 5. View of the upper end of Cuzco Basin from a point overlooking the city of Cuzco. The canyon in the foreground is cut in a gravel fan, which encloses the Basin on the west. Angostura Narrows seen in the distance terminates the basin on the east.

Huatanay⁴ occupies a channel lined by walls of ancient design which lead the stream to the south side of the valley. In this part of its course the water level is maintained by a dam which controls the location of irrigation ditches. From its junction with the Huancaro to a point below San Sebastian the Huatanay is constrained to follow the rim of the Cuzco Basin, thus reclaiming lands otherwise subject to flooding. Below the

FIG. 6.



FIG. 6. The village of San Geronimo at the lower end of the Cuzco Basin showing its position on the margin of an alluvial fan.

mouth of Rio Huilcarpay the stream returns to the center of the valley, following a natural course around the low divide separating the two portions of the Cuzco Basin, and encircling the foot of San Geronimo fan until confined by the walls of the Angostura Narrows. Below Angostura the Huatanay, except where artificially controlled, is a sluggish, meandering stream. For an 8-mile stretch below Saylla, across the flat floors of the Oropesa and Lucre basins (fig. 7), the total fall of the stream is only 160 feet. The quality of the profile of the Huatanay is shown in fig. 8.

Tributaries to the Huatanay vary greatly in amount and permanency of flow. Above Cuzco the streams are moderately

⁴Locally called Rio Zappi.

supplied from springs in the limestone gorges; the western branches within this area contribute little. Within the city of Cuzco the Huatanay receives two canalized tributaries, Chunchullumayo⁵ and Tullumayo,⁶ which have played a prominent part in the history of the city. The Chunchullumayo receives its small perennial supply from a network of branches

FIG. 7.



FIG. 7. Oropesa Basin. View looking east from a point on the cliffs at Angostura Narrows.

issuing from glaciated valleys floored with till and occupied by swamps. In its lower course along the border of the Cuzco gravel fan the stream is supplied directly by ground water which makes good in part for the loss from irrigation ditches. During October 18 springs and seeps, many of them accompanied by landslides, were noted along the lower mile of the Chunchullumayo, and it is probable that more than half of the

⁵The local name for the stream formed by the union of Rio Quilque, Rio Sipaspueyo and Rio Ayahuaycco.

⁶The lower portion of Rio Choquechaca.

run-off originates in this manner. The prevalence of these springs in the suburbs of Cuzco indicates an abundance of ground water—an undeveloped source for much-needed supplies for domestic use.

The Tullumayo, fed by concealed channels in limestone, has cut a trench across the igneous mass at Saesahuaman and drops precipitously into the city, whence it is led through artificial conduits to its junction with the Huatanay. From the ancient fortress to the city streets the fall of the Tullumayo is 400 feet in a horizontal distance of 1,000 feet, or about 2,000 feet to the mile. That the water power thus available was recognized

FIG. 8.

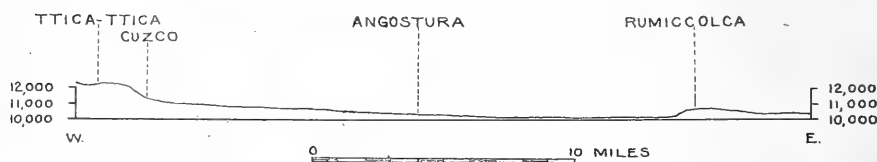


FIG. 8. Longitudinal profile of Rio Huatanay from Ttica-Ttica Pass to the Rumiccolca lava field. The portion of the stream channel from Huacarpay to Sierra-Bella is not shown.

by the Spanish conquerors is indicated by the presence of an abandoned mill flume.⁷

The largest stream entering the Cuzco Basin from the north is Rio Cachimayo,⁸ which rises on the glaciated, grass-covered slopes of the Huatanay-Urubamba divide at an elevation of 13,500 feet and, after flowing for a mile along the southern base of sandstone slopes forming the valley rim, cuts a canyon through limestone pampas and emerges at San Sebastian. Its waters are derived from marshy land at the head of the stream, from rills in the sandstone ridge, but chiefly from springs issuing from cracks in the limestone. The Cachimayo, particularly in its lower course, is heavily charged with chloride of sodium, which is recovered by evaporation at the Government salt works. Several small streams on the porous limestone of Kkallachaca and Era pampas are perennial. In their upper courses swamps and bogs are common, and definite channels are usually absent. On reaching the edge of the basin the water forms continuous rills occupying rock ditches and broken by

⁷ The ruins of the old mill at Saesahuaman have been ascribed to the Incas, but the presence of lead cement, to which my attention was called by Professor Bingham, is inconsistent with such an interpretation.

⁸ The upper portion of this creek is known as Rio Lkalla-Chaca.

falls. Where traversing the basin floor these streams are confined within walls of masonry, which, however, have little function to perform except during periods of heavy rainfall.

The Huancaro is the chief southern tributary of the Huatanay within the Cuzco Basin. Though its drainage area is small, its wide, gravel-filled floor, its moderate, grass-covered slopes, its flat, longitudinal profile, and its position on a fault zone result in a run-off whose uniformity is unusual for this region. Measurements taken during September and again in November, 1912, showed that the Huancaro at its junction with the Huatanay carried more water than the master stream.

The Huanacauri, which joins the Huatanay 1 mile below San Geronimo, is a typical example of the streams entering Cuzco Basin from the south. The lowest half mile of its course is sunk in gravels, and terraces flank the streams for about a mile from its mouth. At a distance of 2 miles the gently sloping, relatively wide valley floor is broken up into a number of sharply cut rock canyons, and at its headwaters the tributary canyons are so numerous and so closely spaced that no undissected land remains. Swamps are lacking; springs are rare; many canyon stretches are dry or occupied by a broken chain of rock-rimmed pools. The surface run-off is very rapid, and stream flow is the immediate and short-lived consequence of showers. The valley form and conditions of run-off along the Huanacauri fairly represent the relations prevailing in the non-glaciated portion of the Cuzco Valley.

Streams entering the Cuzco and Oropesa basins from the lofty northern border of the Cuzco Valley possess certain distinctive features. The Chchiraura is a continuous perennial stream from its source in the Pachatusa cirque to its mouth at Huasau. Its descent is broken by numerous falls, and at the group of herdsmen's cottages after which the stream is named, the floor drops 1,200 feet in the course of half a mile. Rio Huaccoto, rising in the Atascasa highlands, receives its water from a series of glacial deposits deeply mantling the bed-rock over an area of about 3 square miles. In place of defined drainage channels the headwaters of the Huaccoto include lakes, swamps, rills trickling underneath peaty flats, and masses of water-soaked gravels and boulders. At the village of Huaccoto three tributaries unite to form a permanent stream, which at once drops into a canyon with sloping box head and descends to its terminal fan, $1\frac{1}{2}$ miles distant, on a slope of 1,500 feet to the mile. Emerging from the mouth of its

rock-walled canyon the stream, with diminished flow, enters a gravel trench 20 to 110 feet in depth and after a further descent of 500 feet reaches the Huatanay. As regards permanency of flow and the number of tributaries the Huaccoto, draining a glaciated highland, is strongly contrasted with streams from the unglaciated southern rim of the Cuzco Valley.

During the dry winter season—March to November—many of the large streams of the Cuzco Valley are reduced to brooks, some of them become intermittent, and the minor tributaries, except in areas coated with glacial *débris*, cease to flow altogether. Deficient rainfall combined with the demands of irrigation deplete the water to such an extent that during my stay at Cuzco all the streams in the valley could be crossed dry-shod by taking advantage of friendly boulders of moderate size. Even in the Huatanay at San Geronimo stepping stones 6 inches in height were well above water. During the rainy season—December to March—especially in January and February, an enormous amount of water is crowded into the narrow channels to depths of 6 to 10 feet. Where not artificially protected the streams on the valley floor and on the larger fans overflow their banks. Even during the dry season abrupt increase in discharge follows the infrequent but heavy downpours. In spite of the large annual rainfall and the presence of grass on many slopes the conditions of run-off for the Cuzco Valley approximate those characteristic of arid regions. On the flat-lying fertile lands of the Cuzco Basin disastrous flooding is always to be guarded against. That success in restraining flood waters has not been attained is indicated by stretches of gravel-strewn flats, by the abandoned lands above the Angostura Narrows, and by the zones of bare gravel extending across the San Geronimo fan in the midst of terraced fields that are in a high state of cultivation. The fertile, low-lying lands south of San Sebastian, below Saylla and in the Lucre Basin, devoted to pasturage instead of to agriculture, indicate the control exerted by flood waters.

Lakes.—Lakes in the Cuzco Valley are small and few in number. On the floor of the Lucre Basin, which is practically without relief, two permanent water bodies, Laguna de Huaton and Laguna de Lucre, occupy shallow depressions. I am informed that during the rainy season these lakes unite with their bordering swamps to form a body of water nearly 2 miles in length.

On the highland rim of the Cuzco Valley are lakes sunk in glacial *débris*. With a few unimportant exceptions, they

are grouped on the southwest flank of the Pachatucsa and Atascasa mountains and are best developed about the head of Rio Huaccoto. In this region are ten or more lakes occupying kettle holes or perched on the inner slopes of abandoned moraines. All of them are small; the largest water body seen covers less than 2 acres and the average area is but little more than half an acre. The depth of water in the lakes examined did not exceed 6 feet, but water marks at heights of 4 to 10 feet above the surface indicate considerable fluctuation in response to rainfall. The number of water bodies which have been converted into swamps and are now occupied by *Yureta*, the chief peat-maker of southern Peru, exceeds the number of existing lakes.

Solution depressions 25 to 200 feet in diameter dot the surface of the Yucay, Kkallachaca, and adjoining pampas. A few contain water throughout the year; many remain as bogs through the dry season, and high-water marks indicate a large number of water bodies whose life is limited to the season of summer rains.

II. PHYSIOGRAPHY.

REGIONAL RELATIONS.

From a physiographic standpoint Peru is essentially a plateau included between a narrow coastal belt along the Pacific Ocean and the low-lying Amazon Plains. As shown by the regional profile (fig. 3), the surface of the plateau stands between elevations of 13,000 and 15,000 feet, and its borders are sharply marked. Along the line of the railway from Mollendo to La Paz the Peruvian plateau is broken into two segments by the great interior basin holding the waters of Lake Titicaca. The two highlands thus formed in southern Peru may be appropriately termed the eastern plateau and the western plateau, occupying respectively about $\frac{1}{3}$ and $\frac{2}{3}$ of the area included in the Andes Mountains. In northern Peru the highland area narrows and the plateaus are merged; likewise in the latitude of Cuzco the Peruvian plateau is essentially a physiographic unit. As indicated on the diagram (fig. 9) the southwest flank of the plateau is drained by numerous short streams directly tributary to the Pacific Ocean. Heading in valleys of gentle gradient, these watercourses descend rapidly to the coastal plain, where slopes of small inclination are again encountered. Although these streams have cut deep

gorges in the plateau rim and in some places have trenched the upland surface, they are within an arid zone and therefore carry little water to the ocean. The initial topographic expression of the northeast rim of the Peruvian plateau, in a region of heavy rainfall, has undergone extensive modification in consequence of vigorous headwater erosion by tributaries of the Ucayali and the Madre de Dios. In the latitude of Cuzco the surface of the plateau is deeply dissected by the Paucartambo, the Urubamba, and especially by the Apurimac, which carries water to the Atlantic from points less than 100 miles

FIG. 9.

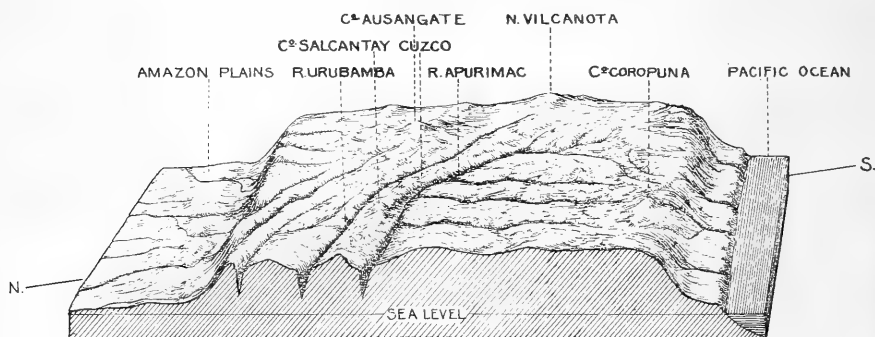


FIG. 9. Diagram of a portion of Southern Peru, including the Cuzco Valley; based on topographic data from all available sources. The block lies approximately between parallels 13 and 16 degrees south latitude. Drawn by Gladys M. Wrigley.

from the Pacific. These major streams crossing the plateau in a northwesterly direction have swift flow interrupted by rapids, but their descent is gentle compared with that of streams on the rim of the plateau. Between its source and its junction with the Urubamba, a distance of about 450 miles, the fall of the Apurimac is approximately 1,400 feet; Rio Majes, which receives its waters from the same area, descends an equal amount in about 90 miles.

As shown on the outline map (fig. 2) the heart of the plateau is attacked by tributaries to the great interior basin. These streams, however, carry no *débris* beyond the plateau borders, and their strength is sapped by a semiarid climate and a high base-level of erosion, the surface of Lake Titicaca, 12,500 feet above tide.

Above a general surface at 13,000 to 15,000 feet the Peruvian plateau is studded by snow-capped peaks attaining heights

of 18,000 to 21,000 feet, and into the plateau surface are cut a number of canyons rivaling the Grand Canyon of the Colorado in depth and ruggedness. In fact so deeply trenched are the highlands, so narrow the spacing between the stupendous gorges, and so commanding the volcanoes and erosion remnants that it is difficult for one in the midst of these features to view the region as a plateau. The sight of the forest is lost in the contemplation of the trees.

When the materials composing the plateau are examined they are found to consist of continental and marine sediments penetrated by igneous intrusions. The sediments have been subjected to widespread disturbance; flat-lying rock is rare. Folds of intricate design are everywhere encountered, and faults are characteristic features. In this expanse of highly disorganized strata the plateau surface has been developed with slight regard to structure. In other words, the Peruvian plateau is an uplifted erosion surface dating from late Mesozoic time. For the purpose of description it will be called the Inca peneplain. As in the case of Bolivia, pointed out by Professor Bowman,⁹ this conception of the Andes is widely at variance with previous interpretations of South American physiography and is quite out of accord with popular descriptions. In the view here taken the bewildering display of lofty peaks and profound canyons, which appear to be arranged in capricious fashion, find their appropriate setting as features of an organized landscape systematically developed. Coropuna, El Misti, and their companions are superposed on the western margin of the Inca peneplain; Ausangate and Salcantay are gigantic examples of erosion remnants formed of resistant rocks etched by vigorous streams on the northeastern slopes of the Peruvian plateau. This interpretation of the physiographic development of southern Peru assigns to the Cuzco Valley its proper relation as a trough of small dimensions sunk below the level of the Inca peneplain.

LAND FORMS IN CUZCO VALLEY.

Factors Conditioning Erosion.

The Cuzco Valley, located between $13^{\circ} 27'$ and $13^{\circ} 40'$ south latitude, is well within the Tropics. The heat incident to low latitudes is to a large degree offset, however, by the high elevation, and the influence of geographic position is reflected chiefly by alternating wet and dry seasons. Scatter-

⁹ This Journal, xxviii, pp. 197-217, 1909.

ing records of precipitation indicate that the number of rainy days in a year averages about 175. May, June, July, and

Precipitation records, Cuzco, collected from various sources. The figures for the year 1895 are considered typical.

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1894								0.01	0.99	3.58	3.18	3.21	
1895	7.01	8.25	5.18	2.68	0.90	0.91	0.29	1.36	1.40	4.53	2.19	6.57	41.07
1909	8.34	2.13	1.93	9.09	1.96		0.28	0.41		1.15	3.09	1.98	30.36
1910	2.49	2.23	5.86	3.89									

August are practically without rain. Weekly rains with cloudy skies are usual for September and October, also for March, April, and to a less extent for May—the autumn months of the Southern Hemisphere. The rainy season begins in November with daily thunder showers, and during January and February precipitation is, in normal years, almost continuous. The discharge of streams during the Peruvian summer is therefore continuous and of large volume, and inasmuch as the cover of vegetation is scant and patchy, particularly on slopes of intermediate height, the run-off is only slightly retarded and vigorous erosion is favored. The sudden fluctuations of streams, due to the heavy, short-lived downpours of spring and autumn, also facilitate the removal of rock débris. As the result of a shower on October 23, 1912, the flow in the Huatanay increased from about 0.30 second-foot of clear water to approximately 8 second-feet of water containing 12 per cent of silt. On the morning of October 29 the Chunchullumayo was a trickling rill, clear except for ever-present sewage; a violent thunder shower accompanied by hail converted the stream into a torrent which undermined banks and redistributed the gravel bars. After the lapse of two hours the water, carrying 18 per cent of suspended red mud, had decreased one-half in amount; next morning the stream had assumed its normal appearance. The relation of run-off to effective erosion is thus seen to be not unlike that prevailing in arid regions.

The temperature of the Cuzco Valley, and hence the effectiveness of rock disintegration from frost, is subject to wide variations. The mean monthly temperatures range from about 41° in July to 54° in November, and the contrast between day and night temperatures is particularly marked. Extreme cold is unknown, but snow on the mountains and ice on standing

water in the lowlands are normal for June and July. At elevations of 12,000 feet the quarrying action of freezing water is probably felt for five months in the year, and above 13,000 feet frost may occur on any night the year round. Snow usually lies on Pachatusca from March to November. However, frost work, as indicated by the amount of talus, is not conspicuous compared with that of colder climates.

Ground water is an active erosional agent in the Cuzco region. Springs and seeps are common along canyon walls and within shallow quebradas. Landslides are very frequent. Within the gravel-walled quebradas adjoining the city of Cuzco eight occurred in a single season. The rock and gravel displaced by slides vary in amount from a few cubic yards to the enormous mass of material represented by the prominent scar on Cerro Picol, which is visible for a distance of 10 miles.

The relief of the Cuzco Valley is favorable for rapid erosion. With the exception of the Huatanay few streams have gradients less than 600 feet to the mile, and considerable stretches of many streams traverse slopes whose inclinations exceed 1,000 feet to the mile. (See fig. 15-20.) In such channels, aided by fluctuating run-off and patchy cover of vegetation, disintegrated materials are rapidly manufactured and easily removed. The erosional work of streams is further facilitated by the calcareous cement of certain strata, by the almost universal presence of open joints, and by the wide extent of partly consolidated glacial and lacustrine deposits.

Mountains.

With the exception of the low volcanic dome of Huaccoto none of the mountain ranges or individual peaks of the Cuzco region retain their original form. They clearly belong to a generation long postdating the great earth movements that gave to the Andes their initial elevation, but they have experienced several cycles of erosion and uplift. The present mountain summits have been carved from truncated edges of folds in which sedimentary strata, chiefly thin-bedded sandstone, have been overturned along sinuous axes. Erosion on the limbs of these complex folds has etched the higher lands into a series of *cuestas* with wide variety of trend and inclination. The crest of the ridge forming the Huatanay-Apurimac divide is in places *serate*, and the dominance of the Apurimac drainage is indicated by the contrast between the steep bare slopes cut

by narrow ravines leading southward and the grass-floored, open valleys tributary to the Huatanay. In the mountains forming the Huatanay-Urubamba divide these contrasted relations are even more noticeable. Pachatusa (15,915 feet) is a cuesta cut from the southern limb of a broad anticline in the crest of which is sunk the canyon of the Urubamba. The southern slope of Pachatusa corresponds with the dip of its component strata; its northern slope truncates the sandstone beds exposed in the precipitous canyon wall of the Urubamba

FIG. 10.



FIG. 10. The crest of Sierra Pachatusa. Elevation 15,915 feet. The precipitous slope on the left descends to the Urubamba. The plateau in the right background is formed of lava.

(fig. 10). The culminating heights of Sencca and the adjoining masses to the east are pyramids and rectangular blocks carved from steeply tilted strata; the twin summits of Cerro Pícol (14,607 feet) are likewise pyramidal masses bordered by glacial cirques (see fig. 31). The jagged sky lines of Maho-Pinta and of Huanaccaurai reveal the presence of rows of teeth and sharp fins weathered from the upturned edges of strata of resistant sandstone.

The mountains coinciding in height with the level of the Inca peneplain are subdued in form, but those above that level present abrupt escarpments, sharply cut canyons, and a variety

of features indicative of mature and youthful dissection. Speaking broadly the mountainous masses of the Cuzco Valley drainage system may be said to have attained maturity. For large areas regional slopes range between 15° and 20° , and slopes of 30° are not uncommon. No mesas exist among the mountains, and undrained interstream spaces are few and small in area.

The unrestricted run-off involved in maturity of mountain form, when expressed in terms of human environment, means

FIG. 11.



FIG. 11. Plateau surface two miles south of Oropesa looking south-east. A. H. Bumstead, photo.

unstable soil. The Incas overcame this difficulty in the more favored localities by terracing the slopes and building retaining walls at an enormous expenditure of time and labor. So skillfully were these masonry structures made that many of them stand to-day in series of ten or twenty, in places over fifty, perched on slopes with inclinations of 10° to 30° , and extending to elevations 800 to 1,000 feet above the valley floors. The present inhabitants find it impracticable to maintain the steeper slopes in tilth, and the agents of erosion have been given new life.

Plateaus.

In the Cuzco region the widespread Inca peneplain has been trenched by the Urubamba to a depth exceeding 5,000 feet and by the Huatanay to an average depth of 3,000 feet below the ancient base-leveled surface. On the southern upland border of the Cuzco Valley a remnant of the Inca peneplain is preserved at an elevation of 13,500 feet over an extent of

FIG. 12.



FIG. 12. Surface of Puquin Plateau, elevation 13,200-13,600 feet, showing geologic structure and character of dissection. Isaiah Bowman, photo.

about 30 square miles (fig. 11). The portion of this area known as Pampa de Huaca-cancha is a local plateau whose surface is made up of a group of low, oblong domes separated by wide, flat-floored valleys. Westward from Huaca-cancha upturned beds of alternating resistant conglomerate and weak shales have permitted intricate erosion, without, however, destroying the plateau form (fig. 12). North of the Cuzco Valley axis the Inca peneplain is represented by the Bambanusa and Huanca-Huanca pampas, whose average elevation is 13,500 feet. The surface of these pampas has been consider-

ably modified by volcanism and by the deposition of glacial débris.¹⁰ The relatively flat-lying area immediately north of the city of Cuzco, embracing the pampas of Pucro, Kkallachaca, Era, Yucay, and Ccorao, with a combined area of approximately 12 square miles, may be called the Limestone plateau (fig. 13). From an elevation of 13,000 feet at the base of Cerro Sencca its surface slopes east and south to the 11,500-

FIG. 13.



FIG. 13. General view of the Limestone Plateau, Pucro Pampa, looking north-eastward across the upper canyon of the Huatanay.

foot contour line. The bedrock on which the plateau is developed is limestone of the Yucay formation, which is believed to owe its preservation to the presence of the Huancaro and Tticapata faults, by means of which a block including the calcareous strata was brought below the general level. It is probable that at the time of regional base-leveling the limestone plateau formed part of the Inca peneplain and that its present position, 1,000 feet below the peneplain, is largely the result of erosion.

¹⁰ See p. 39.

Mature Slopes.

Slopes that have attained a mature stage of development face Huatanay River throughout its length, constituting features of large physiographic significance (figs. 5, 11, 29, 30).

FIG. 14.

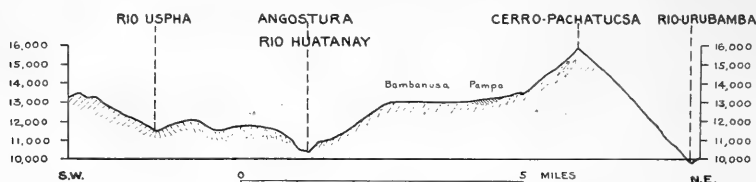


FIG. 14. Profile drawn across Cuzco Valley at Angostura Narrows showing mature slopes truncated at their base and leading upward to plateau surfaces.

As shown on the topographic map and also in the profile sections (figs. 13-18) these slopes bordering the Cuzco Valley axis occupy a zone 1 to 2 miles in horizontal width whose upper limit is the plateau surfaces of the Bambanusa, Huanca-Huanca, and Huaca-cancha pampas, at elevations of 13,500 feet. Both the lower and the upper borders of the zone of

FIG. 15.

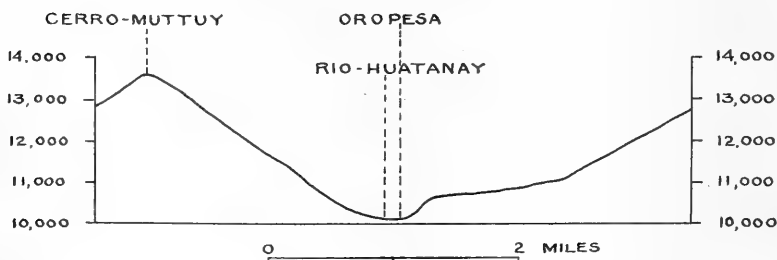


FIG. 15. Cross profile, Huatanay Valley, at Oropesa.

mature slopes are marked by topographic unconformities; at about 13,500 feet mature slopes with inclinations of 1,000 to 1,200 feet to the mile form a contact with a surface sloping about 300 feet to the mile on the Bambanusa Pampa and less than 100 feet to the mile across the Huaca-cancha Pampa. The topographic unconformity at the lower border of the zone of mature slopes is produced by the development of canyon

walls which truncate the slopes at high angles. This feature is well shown at Angostura Narrows (figs. 14 and 20) and also at Huambutio. The relations of these three slopes, developed on rock of essentially uniform composition and structure, require for their interpretation the assumption of three erosion

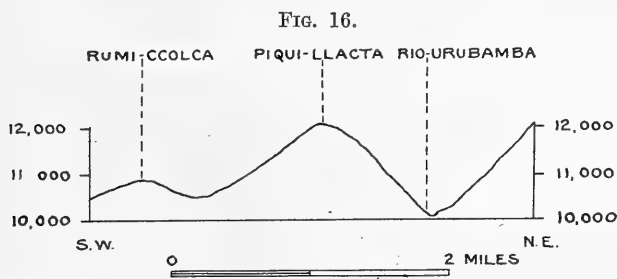


FIG. 16. Cross profile of Urubamba Valley and lower end of Cuzco Valley, drawn through Puquillacta.

cycles—the regional base-leveling of the Inca peneplain, the recent cutting of the present stream valleys, and an intermediate cycle during which the mature slopes were formed.

The lower margins of mature slopes bordering the Huatanay are in most places buried by accumulations of gravel brought

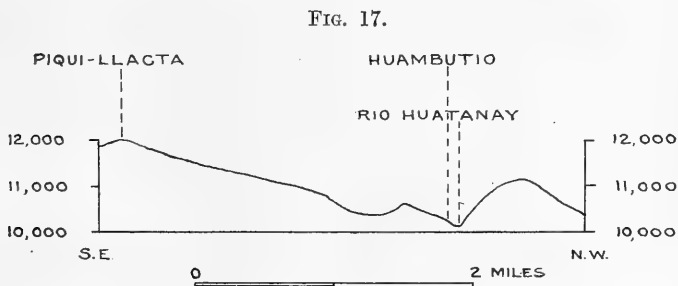


FIG. 17. Cross profile, Huatanay Valley at Huambutio.

down during Pleistocene time by swift streams from the highlands. West of Cuzco and north of San Geronimo, where bedrock is exposed by deep-cut trenches traversing alluvial fans, the mature slopes continue beneath the materials of Pleistocene age.

Valleys.

Huatanay Valley.—The history of the drainage of the Cuzco region can not be written from the facts disclosed by existing field studies. The solution of the problem involves a knowledge of crustal movements and structural relations throughout southern Peru. If the view of the regional physiography presented in this paper¹¹ is accepted, the larger drainage features are readily interpreted; the Urubamba and Apurimac

FIG. 18.

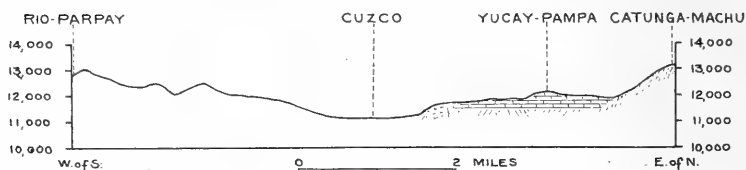


FIG. 18. Cross profile, Cuzco Valley, drawn through the city of Cuzco.

were established on the Inca peneplain and their down-trenching is the result of general uplift; the Pucara and other streams entering Lake Titicaca have found a temporary base-level on the floor of a down-faulted interior basin. If the regional slopes were followed the Huatanay should flow westward to join its master stream, and it is not improbable that during the peneplain cycle the waters from the Cuzco area found their

FIG. 19.

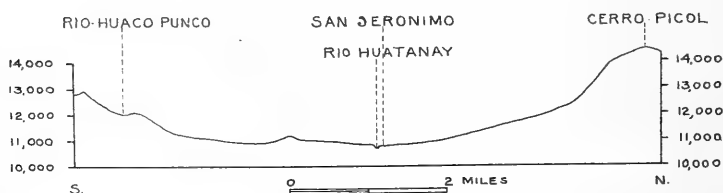


FIG. 19. Cross profile, Cuzco Valley, drawn through San Geronimo.

way to the Amazon through the Ttica-Ttica Pass, whose features as an old-age valley are well marked. The regional uplift of the Andean region was, however, accompanied by warping, by profound and widespread faulting, and doubtless also by the intrusion of igneous rock. The normal course of many

¹¹ See p. 17.

streams was thus interrupted and the initial major features of the Cuzco Valley were developed. That the drainage system of the Huatanay is not young is evidenced by the form of its valley, and by several episodes in its history (described below), each of which involves the lapse of long periods of time; that the Cuzco Valley does not antedate the formation of the Inca

FIG. 20.



FIG. 20. Angostura Narrows showing truncation by recent stream cutting of mature slopes bordering the Huatanay.

penepplain is shown by the remnants of ancient base-leveled surfaces now subject to vigorous attack. The position of the Huancaro fault with uplift on its western border points to a crustal movement that may have determined the western limit of the present Cuzco Valley; faults of the same or of later date are believed to have outlined the course of the Huatanay.

Since its drainage was directed eastward the Cuzco Valley has passed through several episodes whose sequence and significance have not been satisfactorily interpreted. Some of them, however, may be read in the light of physiography. For example, the broad floor of the Oropesa Basin has been cut and again filled by the meandering Huatanay, whose course was temporarily arrested by a lava flow. In a similar manner the ancient outlet of the Huatanay was permanently blocked

FIG. 21.



FIG. 21. The Cuzco Valley at the mouth of the Huatanay looking south across the Urubamba River. Huambutio in middle distance.

by the volcanic flows of Rumiccolca, and the stream was turned abruptly northward over the low pass at Huambutio to join the Urubamba at Sierra-Bella (fig. 21). The Cuzco Basin has experienced successive stages of downwarp and at one period was entirely or at least partly separated from the lower Cuzco Valley and held the waters of an ancient lake.¹² I have been unable satisfactorily to account for the narrows at Angostura. That the region bordering the narrows has been

¹² See p. 34.

subject to intermittent uplift is indicated by a succession of unlike slopes, and that erosion by the Huatanay at this point has had a predominant vertical component is shown by its narrow valley. It is possible that at certain periods in its history the narrows marked the position of a divide, but further study is necessary before the relation of the narrows to the development of the Cuzco Valley can be interpreted.

Contrasted portions of valleys.—The features—peneplain remnants, mature slopes, and truncated spurs—indicating three cycles of erosion, are matched by three unlike portions into which most streams in the Cuzco Valley are divided. For example, the Llampuhuaycco, rising in glacial débris, flows for a mile through an old-age valley, marked by a wide, flat, grass-covered floor in which the stream is neither aggrading nor degrading to an appreciable degree and is carrying little sediment. The middle portion of the stream begins abruptly with waterfalls and rapids and descends precipitously, carrying much sediment along the bed of a narrow rock-walled canyon. Its tributaries drop rills of water from the sloping mouths of hanging valleys. This middle torrent portion is followed by a canyon intrenched in a gravel fan of Pleistocene age. These contrasted portions of the Llampuhuaycco Valley are duplicated in stream channels throughout the Cuzco region.

Relation of valleys to structure.—Most of the streams entering the Cuzco Valley are consequents and owe their position to the topographic slopes. In general they cross the strata nearly at right angles, and their spacing and length are results of initial topographic conditions which determined the shape and extent of their drainage basins. Of the larger consequent streams the Huaccoto is typical. It rises on the Urubamba divide by gathering waters from numerous springs in glacial débris; follows the dip slope to the Huaccoto volcano, which it avoids by a circuitous route; traverses a canyon cut across the strata to Huayllabamba Finca; and reaches the Huatanay by following a depression at the side of the San Geronimo fan. It is everywhere conformable to pre-existing topography and presents no evidence of structural control.

Subsequent streams are represented by many tributaries to northward-flowing consequents on the south side of the Cuzco Basin. The Chchocco branch of the Huancaro has selected for its course the more calcareous beds of a syncline (fig. 22); the upper Huilcarpay and the east branch of Rio Pillau exhibit the same relations. The Uspha is walled for a distance of 2

miles on the north by a single stratum of coarse sandstone of high dip, from which the stream has stripped the less resistant rocks to form a deep gorge less than 100 feet in width. The selection of weaker rock for channels is strikingly shown at the headwaters of this stream, where vertical strata of conglomeratic sandstone stand like teeth in a comb; between the

FIG. 22.

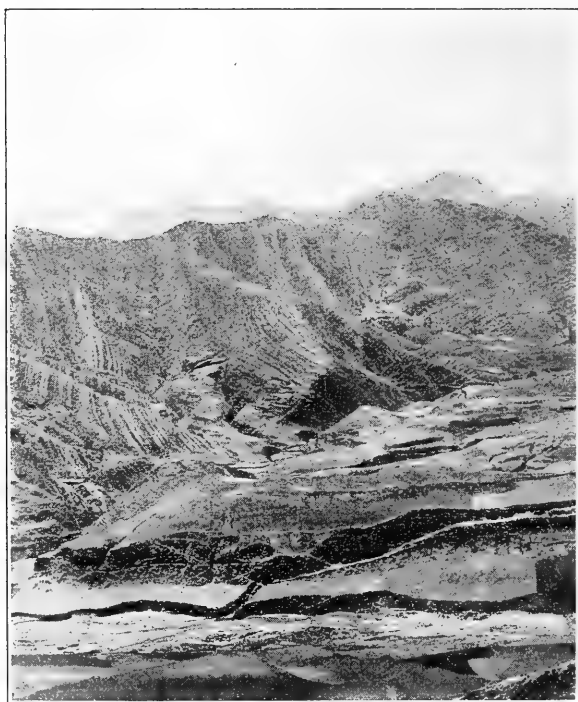


FIG. 22. Valley of Rio Chchocco at its junction with the Huancaro.

teeth are valleys, 4, 6, and 20 feet wide and 10 to 40 feet deep, worn from the less durable beds of shaly calcareous sandstone. The east branch of Rio Kkaira, 2 miles long, draining the back slopes of Sencce-Orcco and Maho-Pinto, also occupies a subsequent valley and when viewed from a favorable point presents an unusually fine example of a valley developed by stripping the back slopes of a hogback (fig. 23). The Lkalla-Chaca has found a favorable location at the contact between

the sandstone of Catunga-Machu and the limestone of the Yuca Pampa. Consequent streams draining into the Oropesa and Lucre basins also have small subsequent tributaries. Numerous small obsequents carry water during the rainy season from the slopes of minor cuestas.

Streams in the Cuzco Valley have taken advantage of the

FIG. 23.



FIG. 23. Valley of the east branch of Rio Kkaira.

major zones of faulting. For at least 3 miles of its course the Huancaro follows a fault line, a fact that partly explains its wide valley floor and its stage of development, which is somewhat more mature than that of other transverse valleys tributary to the Cuzco Basin. The Zappi portion of the Huatanay likewise is located along a zone of faulting. Jointing, commonly associated with minor faults, is well developed in all the rocks about Cuzco. Many joints are open or filled

with weak cement, but their influence in guiding streams has in large part been offset by the steep inclination and complicated folding of the strata, and no dominant control of jointing in valley development is obvious. In a minor way, however, the influence of joints is evident. In three rock canyons where joint direction and spacing were studied the streams were observed to zigzag along the narrow floor, following the larger joints, particularly at waterfalls. In several places, however, a stream has gnawed a groove across a ledge, disregarding the joints near at hand. In spite of the abundance and weakness of joints in the rocks of the Cuzco Valley, their influence on stream alignment is less than in most other regions which have come under my observation, and it appears that control of streams by joints is minimized (1) in steeply inclined strata; (2) in thin-bedded strata of markedly different hardness, in which erosion of weaker beds is easier than widening of joints; (3) in narrow, youthful canyons of steep gradient, where streams once established maintain their courses regardless of structure.

Valleys in unconsolidated deposits.—One of the prominent features of the Cuzco Valley is the large number of canyons and quebradas, cut in gravel and stratified sands. Tributary to the Huatanay at Cuzco are four canyons each exceeding 150 feet in depth, more than a quarter of a mile in length, and not over 1,000 feet in width. They are cut entirely in gravel and have almost vertical walls (fig. 24). On the edge of the limestone plateau at San Sebastian and traversing the fans bordering the valley are many similar examples. That these valleys should have retained their extremely youthful form since Pleistocene time indicates rather exceptional ground-water conditions and also alluvial deposits of unusual compactness. (See pp. 46-51.)

LAKE MORKILL.

The lacustrine strata constituting the San Sebastian formation^{12a} marks the position of a lake which formerly occupied the Cuzco Basin—an ancient water-body whose surface lay well above the present site of San Sebastian and San Geronimo. This vanished sheet of water, for which the name Lake Morkill¹³ is proposed, is believed to have reached its maximum

^{12a} See p. 78.

¹³ Named in honor of W. L. Morkill, a loyal friend of scientific research in Peru. As the representative of the Peruvian Corporation Mr. Morkill has substantially assisted the work of our several expeditions.

expansion in early Pleistocene time. During this period an observer standing at the site of Sacsahuaman would have seen before him an unbroken expanse of water stretching southward

FIG. 24.

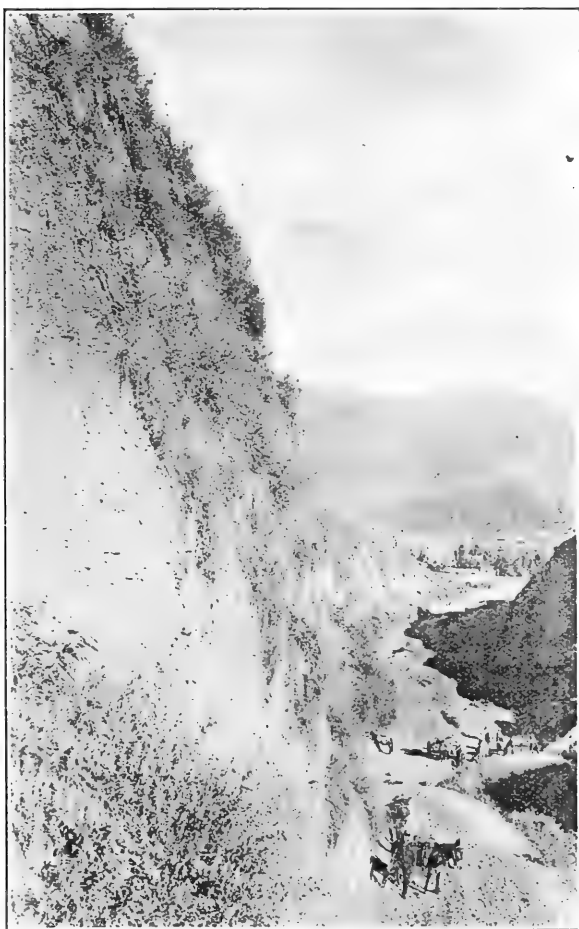


FIG. 24. Canyon cut in gravel. Northeast wall of Ayahuaycco quebrada. Hiram Bingham, photo.

to the Angostura Narrows and overlapping the slopes of the northern and southern walls of the Cuzco Basin. On the left the bays of Huancaro, Ttancarpata, Pillau, and Huanacauri

would have been seen to indent the shore line deeply; on the right the Bay of Tticapata would have been concealed from view by the blunt-headed cape of the Era Pampa. Here and there the regularity of the shore line would have been further modified by low wave-cut cliffs separating deltas of sand and gravel brought to the lake from the bordering highlands. On traversing the strand patches of swamp land and areas of vegetation growing within the shallow marginal waters would have been encountered, and the shells of fresh-water animals could have been gathered from the beach. Mastodon and deer grazing near the lake would not have been an unusual sight.

If the hypothetical observer had been equipped with a sounding line he would have discovered that the west end of the lake was shallow with gently sloping floor extending under water for a distance exceeding a mile. At the east end of the lake a depth of over 200 feet would have been found half a mile from the base of Sencco-Orcco. Along its southern margin a narrow, shallow under-water shelf would have been succeeded by a cliff-like slope leading to deeper water and at nearly all points along the northern shore the sounding line would have indicated 50 to 100 feet of water near land. The site of San Geronimo would have lain about 200 feet below the surface of Lake Morkill and San Sebastian would have been submerged to a depth exceeding the height of the present cathedral.

The order and significance of the various episodes in the eventful life history of Lake Morkill await further study; only an outline sketch can be presented on the basis of existing knowledge.

The basin in which the waters of the lake were originally collected owes its initial form and dimensions to an irregularly shaped, uneven-floored depression developed by faulting during one or more periods. The geologic date of the crustal movements that produced the down-sunken block has not been determined; in fact, it is probable that displacements accompanying regional uplift have occurred at intervals throughout the Tertiary and later periods. The Cuzco Basin postdates the development of the Inca peneplain and may be tentatively assigned to late Tertiary, probably Pliocene time. The down-sunken floor of this early lake basin was partly filled with débris furnished by a number of swiftly flowing streams; at the same time the outlet channel below San Geronimo was deepened. To what extent the lake confined within the original

down-sunken rock basin was drained away and how much its water was shallowed by accumulations on its floor are not indicated clearly by existing geologic features. The narrow gorge at Angostura, still partly filled with Pleistocene gravels, was cut to nearly its present depth during preglacial time; the elevation of its floor, 10,400 feet, is sufficiently low to have permitted the drainage of all ponded water within the Cuzco Basin, provided the present relative altitudes of basin and border prevailed. It is probable that the close of the Pliocene epoch found the Cuzco Basin with a few shallow ponds and swamps united into a sluggish drainage system and surrounded by expanses of sands and silts of a former lake floor. It is possible, indeed, that the Cuzco Basin had reached a stage of completely integrated drainage by the close of the Pliocene and that no bodies of water were to be found in it.

The advent of the Pleistocene was a matter of fundamental importance to Lake Morkill, for during the glacial epoch climatic conditions in the Andes were favorable for aggradation. Waste coating the upper slopes was carried into the valleys in such quantities that the streams were unable to dispose of it, and terraces and deltas and fans of gravel were built on the borders of the depression. At Angostura the rock-walled canyon of the ancient Huatanay appears to have been completely filled with débris to the 11,100-foot contour line, forming a dam that held the waters flowing into the Cuzco Basin and converted the eroded valley floor into a sheet of water whose maximum extension is represented by the boundary of the San Sebastian formation (see map, Pl. II). Lake Morkill was thus given new life. Into this water body were carried the muds and finest sands screened from the masses of waste accumulated along its borders. In large part the material was siliceous, furnished by disintegrated sandstone. Calcareous ooze weathered from the Yucay limestone was also supplied. That Lake Morkill fluctuated in volume in response to changing climatic environment is indicated by alternating beds of limestone, silt, peat, and adobe exposed in nearly all sections of the lake beds. From time to time wide zones of shore were exposed for periods long enough to enable plants to send their roots into the fine materials, for the sun to bake and crack the muds, and for streams to spread gravels over portions of the recovered lake bottoms. Lake Morkill probably existed during all or nearly all of the glacial epoch. Older glacial gravels appear to be interbedded with lake sediments; the

later glacial gravels rest in places on the highest lacustrine strata.

The drainage of the lake was accomplished by cutting down the dam at Angostura—a process that was not continuous, as is indicated by terraces cut in the gravels. Periods of vigorous cutting alternated with periods when sinking of the outlet trench was greatly retarded or even ceased.

Although the history of Lake Morkill thus outlined is believed to include the major events, two factors remain to be evaluated—the extent to which the lake was obliterated by filling and the effect of crustal movements expressed in the distortion of the lake beds. The filling must have been considerable, for the lake basin is less than 2 miles in width, the bordering slopes are steep and thoroughly drained, and the amount of débris as indicated by existing deposits is enormous. The original position of the lake beds—horizontal along the valley axis, gently sloping lakeward along the ancient shores—has been modified along the northern shore by later movements. North of San Sebastian the dip of the lacustrine strata reaches a maximum exceeding 15° ; the beds are traversed by numerous faults with displacements measured by a few inches, bringing the northern portion of the beds above the southern. The uppermost strata as well as those below have suffered modification, indicating that the movements, in part at least, were later than the time of maximum expansion of the water body and could therefore have had little effect in producing the basin itself.

Estimates of the duration of the life of Lake Morkill measured in years are of little value, because the rate of accumulation of limestone, of peat, of sands, and of adobe is subject to wide variations, and until the beds on the north shore of the lake have been correlated with those on the south shore no reliable data regarding periods of retreat and advance of the waters can be obtained. That the sheet of water existed while glaciers still scored the slopes of Seneca and Patchatusca is indicated by the fact that early glacial gravels at least are interleaved with lacustrine deposits; gravels of a second glacial epoch are piled about the ancient coast and their local accumulation resulted in raising the lake levels or perhaps even in forming the lake itself. Beginning in Pliocene time, the lake is believed to have existed with many and large changes in volume to the close of the last stage of ice advance. With the decrease in the supply of waste following the retreat of the

ice final down-cutting of the outlet and removal of the accumulated lake sediments began, a process continuing to the present time.

Lake Morkill is one of a number of ancient fresh-water bodies occupying depressions in the Inca peneplain of southern Peru which await investigation. The only one heretofore studied presents features closely similar to those found in the Cuzco Basin.¹⁴

GLACIATION.

Introduction.

The position of the present snow line in southern Peru has been determined for only a few places. Even less is known regarding the position of existing glaciers and of the moraines formed in Pleistocene time. Extreme views are held by Hauthal,¹⁵ who expressed the opinion that no general Pleistocene glaciation occurred in Peru, and by Dueñas,¹⁶ who considered the Cuzco Valley at elevations of 11,000 feet and below to have been occupied by ice. Adams¹⁷ placed the lower limit of glaciers in the Poto region of southern Peru at 2,500 feet above the ice fields of the glacial periods.

No glaciers exist within the drainage basin of the Cuzco Valley, and no perennial accumulations of snow are to be found even at an elevation of 15,915 feet, the culminating point on the valley rim, but snow rests on the highest summits well into summer. After showers Picol and Pachatusca and Seneca may be mantled with snow during the warmest months, and on rare occasions the lower slopes and even the floor of the valley are coated with white late in the spring and early in autumn. During the glacial period all the higher peaks and ridges were snow-capped and tongues of ice occupied the heads of many valleys tributary to the Huatanay. The lowest undoubted deposits resulting directly from ice action stand at approximately 12,500 feet. Several well-developed moraines were mapped at 13,000 feet, and the valley profiles at this elevation indicate the presence of ice. Above 13,500 feet the landscape at all points has been molded by ancient glaciers and

¹⁴ Gregory, H. E., *Geologic reconnaissance of the Ayusbamba (Peru) fossil beds*; this Journal, xxxvii, 125-140, 1914.

¹⁵ Quatare *Vergletscherung der Anden in Bolivien und Peru*, Zeitschr. für Gletscherkunde, i, p. 203, 1906.

¹⁶ Dueñas, *op. cit.*, 1907.

¹⁷ An outline review of the geology of Peru, Smithsonian Inst. Report for 1908, p. 409.

cirques at valley heads, and lake-dotted morainal accumulations are characteristic features. For the Cuzco region as a whole the lower limit of Pleistocene ice may be placed at an elevation between 12,500 and 13,000 feet, its position between these levels depending on the topography. These figures for the

FIG. 25.



FIG. 25. Moraines at La Raya Pass.

limit of glacial action in the Cuzco Valley do not apply generally to southern Peru. Diverse conditions prevail on opposite sides of mountain crests, and even within a single valley the terminal moraines are at widely different elevations. Along the Urubamba the prominent moraines at La Raya, 110 miles (178 kilometers) southeast of Cuzco (fig. 23), lie high above the railroad, which at this point has an elevation of

14,235 feet; but between Ollantaytambo and Torontoy, 40 miles northwest of Cuzco, "well-developed terminal moraines at least 400 feet high stand but 8,500 feet (aneroid) above sea level."¹⁸

Unpublished topographic maps of the Peruvian Expeditions of 1911 to 1914 give trustworthy figures for the position of the present glaciers and of Pleistocene moraines at Salcantay, in latitude $13^{\circ} 20'$ south. On the north side of this mountain group the ends of the glaciers rest at 14,500 feet and the lowest moraine lies at 11,100 feet; for the east side the corresponding figures are 14,300 and 11,200 feet, and for the south side 14,300 and 12,200 feet.

Glacial Features North of the Cuzco Valley Axis.

The east-west trend of the Cuzco Valley gives to its opposite sides unequal exposure to the rays of the sun. It is, therefore, to be expected that northward-facing slopes in this latitude should present less evidence of glaciation than slopes facing southward. When the highlands forming the valley rim are examined, this assumption is found to be in accord with the facts.

Along the north rim of the Cuzco Valley the evidence of ice action is unmistakable and glacial features retain their original expression with only slight modification. Streams flowing from Sencca, Fortaleza, and Catunga-Machu head in cirques and flow between stretches of lateral moraines 1,000 to 2,000 feet long and 10 to 50 feet high. On the southwest slope of Sencca cirques between 13,500 and 14,000 feet are plainly visible from the valley below. In the upper reaches of the Rio Muyo-Oryco, where the direction of ice movement is at right angles to the strike of jointed sandstone, a flight of four steps was noted with risers 5 feet to 60 feet in height. The largest tread has an area of about 1 acre; the smallest, of 300 square feet. Two of the treads are overdeepened and retain ponds on their striated floors. A series of terminal moraines, the lowest at about 13,500 feet, are trenched by the northern tributaries of the upper Huatanay, and ground moraines with uneven surface occupy interstream spaces. The projecting ledges of sandstone as well as of limestone are poorly adapted to retain striae, and the effect of glacial scour on dividing ridges is scarcely perceptible. A remarkable

¹⁸ Bowman: The Geological Relations of the Cuzco Remains, this Journal, xxxiii, p. 317, 1912.

imitation of glacial striation is seen on the Rodadero, at an elevation of 11,750 feet (fig. 26). The grooves and striae and polished surfaces on this intrusive mass of augite diorite are in fact so closely similar to features produced by ice that it occasions no surprise to find them generally used as proof of glaciation. When, however, the Rodadero is studied in detail, the "glacial markings" are found to have been developed by faulting.¹⁹

FIG. 26.

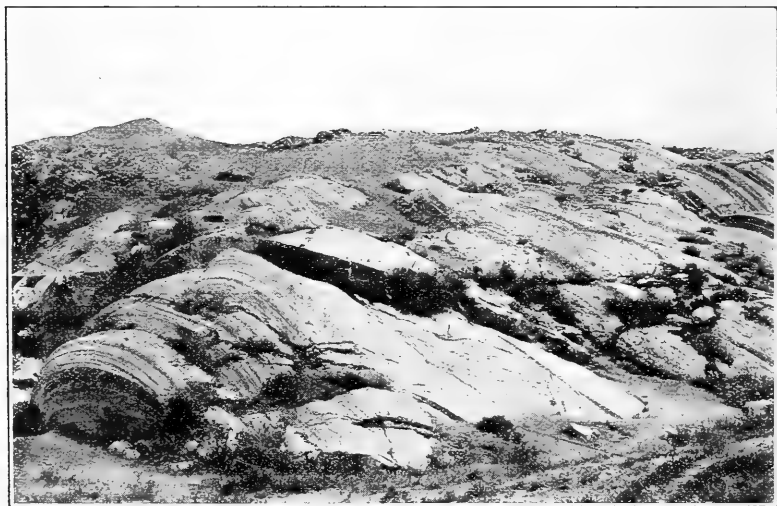


FIG. 26. El Rodadero, near Cuzco. Hiram Bingham, photo.

The twin peaks of Cerro Picol are bordered by cirques whose characteristic features are well expressed. Below the pyramidal summits grass-cloaked or bare, striated rock platforms bordered by precipitous inner walls testify to vigorous glacial plucking. On the lip of a cirque facing Ccorao an unbroken moraine rises to a height of 400 feet, inclosing a basin of about 30 acres. The time elapsing since the retreat of the ice from Picol has not been sufficient for the development of surface drainage within the cirque, and water collected on its swampy floor escapes by seepage to find its way to the Urubamba. As viewed from Cuzco, 7 miles distant, this walled

¹⁹ Gregory: The Rodadero; A Fault Plane of Unusual Aspect, this *Journal*, xxxvii, pp. 289-298, 1914.

cirque has the appearance of a crater and has doubtless given rise to the erroneous belief that Cerro Picol is volcanic.

Bedrock about the headwaters of Rio Huaccoto and extending north to Cerro Atasccasa is almost completely cloaked with glacial débris. Eight moraines, 500 to 3,000 feet in length, were noted along the borders of flat-floored, smooth, grass-covered valleys leading southward to the edge of rock-walled canyons. Striated boulders attaining diameters of 4 feet and more, plucked from ledges of igneous and sedimentary rocks, strew the surface. Within an area of about 6 square miles the till is very unevenly spread; depressions between interlocking moraines are common, small lakes and swamps occur, and no definite lines of drainage have yet been established.²⁰

Glacial features of large variety and unusual freshness are displayed in the region drained by the Chchiraura. North of the tiny group of herdsmen's cottages known as Ccasa-Cancha the stream consists of two branches which surround the igneous mass of Ichchu-Orcco. The western branch rises in a swamp whose basin has been overdeepened by ice. It has the typical features of a glaciated valley and is bordered in part by banks of morainal material and in part by rock walls. Exposed ledges of andesite are scoured and striated on both horizontal and vertical surfaces. Erratics are abundant on divides at 13,500 feet and are found to a small extent at 13,000 feet and below. The terminal moraine has been almost completely removed. The south branch of the Chchiraura rises in a rock-walled cirque nearly square in ground plan, perched high on the flank of Pachatucsa, 14,500 to 15,500 feet above sea level. The floor of the cirque dips to the south at an angle of 20° and descends by giant steps with scoured treads from the inner edges of which huge blocks have been removed and carried to lower levels. Patches of ground moraine and irregular masses of marginal moraines are distributed over the bare rock floor at the mouth of the cirque, and the base of the slope at 13,500 feet is plastered with a mass of till, the remnants of the youngest of a series of terminal moraines.

Below the lip of the cirque the valley extends as a wide, smooth-floored, flat trough bordered by walls which rise steeply to heights exceeding 400 feet (fig. 27). The gradient of the floor is scarcely sufficient to carry the stream, which, beginning as a swamp, meanders through boggy flats, passes two recessional moraines, and finally emerges from the lowest moraine as

²⁰ See p. 15.

rapids confined by closely spaced gravel walls. The two recessional moraines looped on the valley floor are 20 feet and 6 feet high; the moraine marking the farthest advance of the ice during the last period of glaciation is a V-shaped wall of débris 150 feet in height which stands at an elevation of about 13,100 feet (fig. 28).

Patches of ground moraine in this area are found below the terminal moraines, and valleys modified by ice extend to the 12,500-foot contour line and at that level hang above

FIG. 27.



FIG. 27. Glaciated Valley near headwaters of Rio Chchiraura.

deep-cut canyons trenching the mature slopes descending southward to the Huatanay. Though somewhat difficult of access, this locality is well worth a visit by those interested in Pleistocene geology.

Glacial Features South of the Cuzco Valley Axis.

The glacial features on the southern margin of the Cuzco Valley are less prominent and less well preserved than those on the northern rim above described; the southern ice cap was thinner and shorter-lived. No lateral or terminal moraines

were observed in valleys heading at Sackkaira and Puna-Cancha, no well-defined cirques were found at valley heads, striae and ice-worn boulders are exceedingly rare, and evidence

FIG. 28.



FIG. 28. The lowest of a series of three moraines in the Chchiraaura Valley.

of glaciation consists mainly of valley form. The headwaters of the Qquilque, the Occopata, the Huilcarpay, the Uspha, and streams which have their sources in the Huaca-Cancha

Pampa occupy smooth-floored, steep-sided depressions with the flat longitudinal profiles characteristic of glaciated valleys. Many of the notches in the southern highland rim are cols on which ice tongues leading toward the Cuzco Basin united with those directed toward the Apurimac. Ground moraine, largely covered with débris washed from the valley sides, is exposed here and there along certain streams which make their way through swamps and gravelly flats. Below elevations of about 13,000 feet the glacial features disappear; the flat valley floor is replaced by a deeply trenched ravine whose marginal walls are intricately dissected. On interstream areas between 13,000 and 13,500 feet imperfectly drained flats and stretches of swamp occur and incipient moraines border the highest knobs—suggesting that ice or at least névé formed a continuous sheet at these elevations.

Glacial Gravels.

Distribution and character.—The swing of the climatic pendulum which introduced the ice age appears also to have initiated a period of increased rainfall. Streams were thereby increased in volume and their erosive power was greatly augmented. The significance of this change of stream habit is readily appreciated when we watch the action of streams following heavy showers and realize the havoc that would be wrought even to-day by maintaining at flood stage the streams on the steeply inclined slopes of the Cuzco Valley. The opportunity for collecting waste from the highlands is much less favorable now than formerly, because large areas of the valley sides consist of firm or slightly disintegrated rock. At the close of the Pliocene epoch the slopes were probably deeply coated with waste which had been accumulating for ages, and the enlarged streams of early Pleistocene time found vast quantities of material ready for transportation. The thoroughness with which these streams performed their task of removing superficial material is indicated by the wide belt of practically bare rock now displayed along both sides of the valley axis.

The materials stripped from rock on the upper slopes was transferred by streams of glacial time to the floor of the Cuzco Valley and to its bordering lower slopes. The amount carried into the Cuzco Basin and added to the bottom deposits of Lake Morkill is unknown, for later erosion has removed much of the valley fill and cut deeply into the lacustrine sediments. The deposits on the lower slopes, however, are exposed for

study. The Cuzco Basin is bordered by an almost continuous terrace of gravel overlying and interbedded with adobe, sand, and limestone—the cut edges of fans and quiet-water deposits, now elaborately dissected (fig. 29). The Oropesa and Lucre basins contain accumulations of gravel, and beyond the limits of the Cuzco Valley dissected fans and gravel terraces are prominent along the Urubamba and Apurimac drainage systems.

Two compound fans of unusual dimensions—Cuzco and San Geronimo—are shown on the topographic map. The Cuzco

FIG. 29.

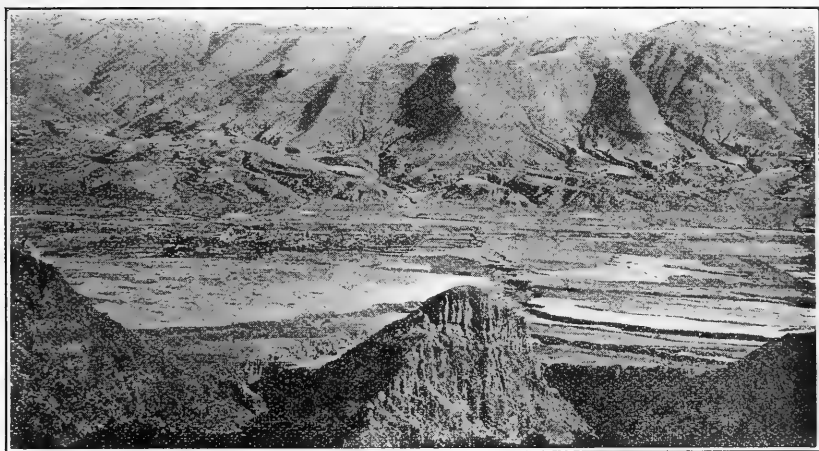


FIG. 29. Dissected terraces south side of Cuzco Basin, looking across the village of San Geronimo from the base of Cerro Pícol. A. H. Bumstead, photo.

fan, on whose lower slopes the ancient Inca city was built, has a length of $2\frac{1}{2}$ miles and a maximum width exceeding 1 mile. The surface of the upper portion is nearly flat; the lower portion has a slope of 200 feet to the mile. Canyons exceeding 150 feet in depth are sunk into the gravel without reaching the base of the deposits. The accumulation of gravel at this locality is favored by the topography, for a narrow preglacial valley at elevations of 11,000 to 11,500 feet is bordered by walls which attain heights exceeding 14,000 feet in a distance of less than 3 miles. The structure, composition,

and physiographic history of this fan have been fully described in a previous paper.²¹

The San Geronimo fan is formed of enormous quantities of land waste washed from the slopes of Cerro Pícol and deposited on the floor of the Cuzco Basin. The alluvial sediments thus supplied extend nearly across the Cuzco Valley and are responsible for the existence of the agricultural community centered

FIG. 30.

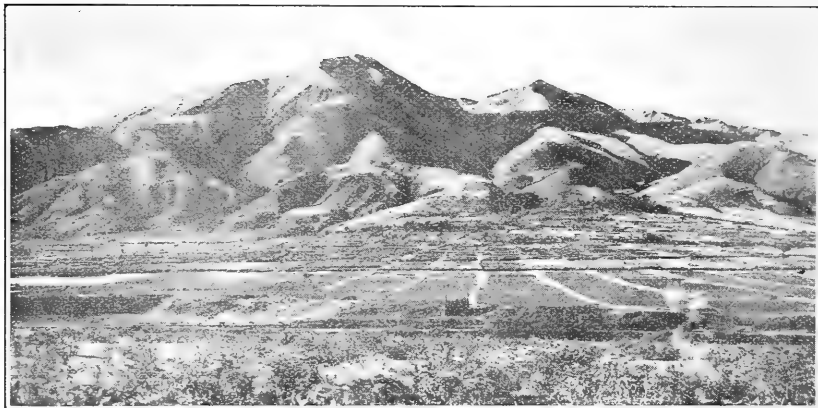


FIG. 30. The San Geronimo fan extending south from the base of Cerro Pícol. A. H. Bumstead, photo.

at San Geronimo. Measured along Huatanay River the foot of the San Geronimo fan is 4 miles long; its width from the base of the rock slopes southward to its periphery is a little less than $1\frac{1}{2}$ miles. Its surface slopes about 450 feet in a mile. As seen in the photograph (fig. 30), the fan has received its gravels from the streams traversing the steep middle slopes of Cerro Pícol—streams which head in cirques and glaciated valleys leading from pyramidal summits. From the crest of the mountain (14,607 feet) to the head of the fan (11,500 feet) these streams descend at the rate of about 1,600 feet to the mile. At the present time the mountain slopes are almost bare, and little material is carried by the swiftly flowing brooks. In fact, the streams traversing the fan are now intrenching themselves near the mountain base, and their work

²¹ Gregory, The gravels at Cuzco, Peru, this Journal, xxxvi, pp. 15-29, 1912.

is confined largely to transporting gravel from the head of the fan to its lower margin, where deposition is progressing to such an extent that many ancient fields have been buried.

At Angostura Narrows the Ayahuaycco and Llampuhuaycco, rising in the Bambanusa Pampa, aided by streams from Sencco-Orcco, deposited gravels in the preglacial gorge, completely blocking the channel. On the north side of the valley much of this gravel remains as a dissected terrace whose front is over 200 feet in height and whose top forms a table at an elevation of 11,100 feet.

The assignment of the piedmont gravels of the Cuzco Valley to late Pleistocene time rests on the following observations:

(1) The deposits were obviously not laid down under present conditions, for they are now undergoing dissection. Their interpretation demands the assumption of climatic and soil conditions favorable for vigorous erosion of waste-cloaked upper slopes and rapid aggradation of lower slopes and valley floors. The inference that Pleistocene time provided these conditions for most localities is supported by world-wide observations.

(2) When traced up valleys in which the deposits have not been obliterated by erosion, the gravels are found to interlock with materials whose glacial origin is unquestioned.

(3) As regards degree of freshness of material and amount of dissection the Cuzco gravels differ in no essential from piedmont deposits of Switzerland, the Sierra Nevada, and the Rocky Mountains, whose Pleistocene age has been demonstrated.

(4) The close association of the piedmont gravels with well-defined glacial remains, the shallow weathering of the deposits, and the insignificant amount of more recent waste overlying the fans and terraces support the belief that the gravels are contemporaneous with the moraines and cirques of the highlands and belong to the latest period of glaciation represented in the Andes, an ice age which may tentatively be correlated with the late Wisconsin epoch of North America. Patches of an older till-like material beneath the moraines of the Bambanusa Pampa and beds of poorly sorted gravel interstratified with the lacustrine deposits in the Cuzco Basin suggest that sediments laid down during an earlier cycle of glaciation are preserved in the Cuzco region. The evidence for this assumption is, however, inconclusive.

Postglacial erosion of gravels.—With the retreat of the ice from the Cuzco Valley the removal of glacial deposits began. Streams which formerly united to build a fringe of gravel fans

about the Cuzco Basin now undertook to destroy their previous work. Degradation, heretofore active on the upper slopes, was extended to the lower slopes, and aggradation was halted even on the valley floor. The time elapsing since this change

FIG. 31.



FIG. 31. Wall of canyon, 100 feet deep in lacustrine deposits, one mile north of San Sebastian.

in stream habit has not been sufficient to remove all waste from the lower slopes and to redistribute the piedmont materials, but the work already accomplished is large in amount. All tributaries to the Huatanay have partly re-excavated their

channels; on a few of them the work is complete. The fans are trenched with canyons which compare in depth with adjoining rock-walled gorges. Above Cuzco the Huatanay (Zappi) has again reached bedrock and the entire Cuzco fan is dissected by straight-sided, gravel-walled trenches 100 to 200 feet in depth (figs. 5, 13, 24). A section of the San Geronimo

FIG. 32.

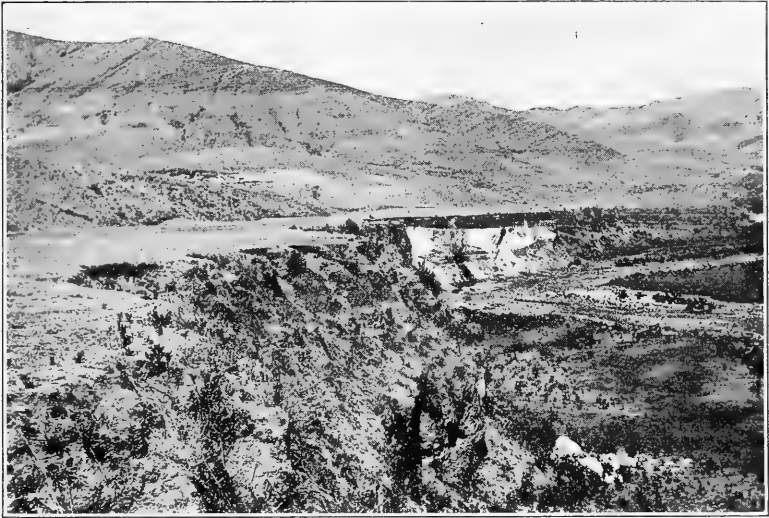


FIG. 32. Terraces along the Huatanay, at Condor-Roma, cut in ancient lacustrine deposits.

fan reveals the presence of a series of narrow, flat-bottomed, vertical-walled gravel canyons intrenched to a depth of 100 feet, without, however, reaching strata of preglacial age. Likewise the tilted lake beds adjoining the village of San Sebastian are deeply trenched (fig. 31). At Angostura Narrows bedrock has been exposed by the removal of about 600 feet of gravel (fig. 20), and along the south side of the Cuzco Basin dissection of piedmont gravels and lake sediments is unusually conspicuous (fig. 29).

Terraces.—That postglacial erosion has not continued at a uniform rate but has been subject to marked fluctuation and interrupted by periods of aggradation is indicated by a widespread development of terraces. Along the upper Huatanay

a flight of three terraces was seen. The lowest step, 8 feet above the stream, is cut in rock; the other two are developed on gravel at elevations of 12 to 20 feet and 50 to 60 feet respectively above the valley floor. At the mouth of the

FIG. 33.



FIG. 33. Group of terraces at Ttancarpata.

Huatanay the terrace 12 feet above the stream again appears. The terraced bank of the Huatanay below the mouth of the Huancaro is shown in fig. 32. At this locality the flat floor of the lowest terrace is practically undissected; the second terrace is trenched by quebradas. The material of both terraces is lacustrine in origin, and the foot of the upper terrace is

believed not only to represent a former level of the Huatanay but also to mark the shore line at a stage in the life of Lake Morkill. A flight of dissected terraces, three in number, the highest at 11,100 feet, flanks the Huanacauri for a distance of 2 miles above its mouth. The largest number of well-developed terraces preserved in the valleys about Cuzco is five; the smallest, two. A typical group of terraces for the smaller tributaries to the Huatanay is illustrated in fig. 33.

In the Ayahuaycco Quebrada and certain other steep-walled canyons no terraces were seen, but these exceptions to the common pattern are not significant, because conditions in narrow trenches with very steep bordering slopes are unfavorable for the preservation of terraces. Moreover, many terrace flats have been modified as the result of irrigation and the construction of *andenes* during the centuries of human occupation.

Additional proof of climatic fluctuation which resulted in the alternate deposition and removal of alluvium involved in the construction of terraces is afforded by the presence of series of recessional moraines, three to five in number, which cross the floors of glaciated valleys.²² It is probable that detailed study would result in the correlation of the terraces and moraines and furnish the necessary data for writing the climatic history of the Cuzco Valley from the close of the glacial age to the present. The result of canalization of streams to prevent flooding and the realignment of channels designed to reclaim valley flats must, however, be taken into account. Much to my regret the demands of other work prevented a study of recent physiographic history and its relation to the Inca population.

III. THE SEDIMENTARY ROCKS.

INTRODUCTION.

The sedimentary rocks of the Cuzco Valley and adjoining areas between Urubamba and Apurimac rivers consist essentially of Mesozoic strata intricately folded and traversed by innumerable faults of large and small displacement. The complicated structure of these rocks, which are widely variable in composition and texture, requires detailed study of a high degree of refinement before a satisfactory analysis of the stratigraphic column can be presented. On the basis of the recon-

²² See p. 41.

naissance examination eight groups of strata have been tentatively outlined. For purposes of description these are classified as follows:

Recent—Gravels, sands, travertine.

Pleistocene—Glacial gravels; moraines; lacustrine deposits.

Pleistocene-Pliocene—San Sebastian formation: Lacustrine sands, clays, limestones.

Tertiary (?)—Volcanic rocks: Andesite and basalt. Bambanusa formation: White and pink friable quartz sandstones.

Upper (?) Cretaceous—Yucay formation: Blue-gray brecciated limestone.

Jura-Trias (?)—Huayllabamba formation: Red and brown thin-bedded sandstone and arenaceous shales. Molle-Orcco conglomerate member: Coarse sandstone and conglomerate. Pachatucsa formation: Brown volcanic conglomerates and sandstones.

Permian (?)—Qquilque formation: Brown and gray sandstones, limestone conglomerate, and gypsum.

The age of only one of these stratigraphic groups, the Yucay formation, is directly proved by paleontologic evidence. The presence of characteristic glacial deposits is the basis for the assignment of the great accumulations of undisturbed gravels to the Pleistocene. The date of deposition assigned to the lacustrine sediments constituting the San Sebastian formation rests on physiographic relations, supplemented to a slight degree by evidence from fossils. The position in the time scale of the Bambanusa, Huayllabamba, Pachatucsa, and Qquilque formations has not been satisfactorily determined. The basis of subdivision is lithologic dissimilarity, little known structural relations, and a meager knowledge of the regional geology of southern Peru. The shales in the basal beds resemble in certain respects the Carboniferous (Pennsylvania) strata of Lake Titicaca,²³ but coal, massive limestones, and heavily bedded gray sandstones are absent, and marine fossils, so abundant at Titicaca Island and Copacabana, were not found at Cuzco. It is not improbable that the formations provisionally classed as Permian (?) and Jura-Trias (?) may have originated in one geologic period, and the system to which they are ultimately assigned may be any part of the stratigraphic column from Carboniferous to Lower Cretaceous.

²³ Gregory, H. E., Geological sketch of Titicaca Island and adjoining areas, this Journal, xxxvi, pp. 187-213, 1913.

QUILQUE FORMATION.

As displayed in the field the strata included in the Quilque formation are bounded on the east and north by the Huancaro fault; in other directions the formation extends beyond the limits of the area mapped. Although showing numerous small folds with variously oriented axes the beds in general form an anticline trending approximately north. The dips on the east limb of the major fold reach angles exceeding 80° ; high dips prevail also on the west limb but decrease in amount with increase of distance from the central axis. Alternating beds of brown sandstone and chocolate-colored shale are exposed on the two limbs; the truncated crest includes beds of limestone conglomerate and of gypsum. Unequal resistance of the various strata has determined the lines of major drainage; the broad upper valley of the Quilque in particular appears to owe its position and form to the weathering of soluble beds. The character and arrangement of strata in the upper portion of the Quilque formation is shown in the following section of the east limb of the anticline.

I. Section of upper beds of the Quilque formation in an area of intricately folded strata along the Ferrobamba trail, beginning three-quarters of a mile from the mouth of Quilque Quebrada.

Average strike approximately north; dip 30° E- 90° .

Top.	Feet.
1. Sandstone, brown, fine to medium grained; quartz grains with calcareous and argillaceous cement; beds 4 to 5 feet thick, subdivided by fine lines or stripes of darker material; lenses and pellets of clay common; much secondary lime along joints	80
2. Shale and argillaceous sandstone; red to chocolate; calcareous in places; highly variable in texture, composition, and structure	8
3. Sandstone, brown, calcareous, lenticular and nodular	1
4. Shale and argillaceous sandstone, like No. 2; in places recemented bits of fine sandstone	4
5. Sandstone, brown, calcareous, fine grained; minutely striped and cross-bedded; beds displaced 3 feet by a fault trending, about east	1
6. Shales, light red to chocolate; calcareous; irregularly bedded; resemble compact weathered sandy clay, rearranged by pressure	10
7. Sandstone, brown, like No. 1	4

	Feet.
8. Shale, chocolate, like No. 6	9
9. Sandstone, brown, like No. 7, but crumbly, nodular, highly argillaceous, and minutely cross-bedded	7
10. Shale, chocolate, like No. 6	6
11. Sandstone, brown, like No. 1; much cross-bedded ...	9
12. Shale, chocolate, like No. 6	12
13. Sandstone, brown	4
14. Shale, chocolate	1
15. Sandstone, brown	1
16. Shale, chocolate	2
17. Sandstone, brown, much cross-bedded	13
18. Sandstone, light gray; weathers yellow-gray; uniform medium grain; very thin-bedded, cross-bedded; a patch or lense on bottom of bed No. 17	1
19. Shale, chocolate, highly arenaceous	8
20. Sandstone, gray, cross-bedded, thin-bedded, uniform medium grain; calcareous cement; apparently dif- fers from No. 7 only in color	4
21. Shale, chocolate	12
22. Sandstone, brown, like No. 1	9
23. Shale, chocolate, with 4-inch band of brown sandstone	5
24. Sandstone, gray, friable, calcareous, with arenaceous and calcareous concretions; weathers bright yellow on upper surface	5
25. Shale, red to chocolate	4
26. Sandstone, brown, with bands of paper-thin shale near top	3
27. Shale, chocolate, with 1-inch bands of brown sandstone and half-inch lens of blue limestone	4
28. Sandstone, brown, with 1-inch cap of gray sandstone	4
29. Shale, chocolate	4
30. Sandstone, brown	3
31. Shale, chocolate	2
32. Sandstone, brown, capped with thin layer of gray sand- stone	2
33. Shale, chocolate	1
34. Sandstone, brown	1
35. Shale, chocolate	5
36. Sandstone, brown	1
37. Shale, chocolate, and brown sandstone, in alternating beds, 2 to 3 inches thick	6
38. Sandstone, brown	3
39. Shale, chocolate	7
40. Sandstone, brown, extremely thin-bedded and cross- bedded	15
41. Shale, chocolate	6

Feet.

42.	Sandstone, brown, very fine, minutely cross-bedded; calcareous cement; vertical tubes like worm holes; carbonaceous patches; surface sun-baked and with imperfect mud cracks; mud lumps and tiny lime concretions on surface	0.5
43.	Shale, chocolate; sun-dried surfaces; flakes of muscovite	5
44.	Sandstone, brown	1
45.	Shale, chocolate	3
46.	Sandstone, brown	7
47.	Shale, chocolate	2
48.	Sandstone, brown	1
49.	Shale, chocolate	1.5
50.	Sandstone, brown	1
51.	Shale, chocolate	2
52.	Sandstone, brown and gray bands	3
53.	Shale, chocolate	6
54.	Sandstone, brown, with 1-foot layer of gray sandstone at top	9
55.	Shale, chocolate	1
56.	Sandstone, brown	1
57.	Shale, chocolate	12
58.	Sandstone, brown	4
59.	Shale, chocolate	10
60.	Sandstone, brown	4
61.	Shale, chocolate, with thin bands of sandstone	14
62.	Sandstone, brown; sun-baked surfaces and ripple marks	1
63.	Sandstone, gray	1
64.	Sandstone, brown, interbedded with chocolate shale ..	50
65.	Interval (estimated)	100
66.	Limestone conglomerate, gray to blue-gray; chiefly concretionary pebbles and irregular fragments of limestone, the size of small shot to half an inch in diameter; a few chert pebbles; bed lenticular; top not exposed	4
67.	Sandstone, gray to yellow-green; medium-grained quartz; thin-bedded, cross-bedded; includes thin sheets of finely laminated shale	15

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Most of the beds in Section I do not retain their individuality for more than a few hundred feet; overlapping lenses rather than widely extended layers of uniform thickness constitute the bedrock, and the strata themselves, in many places, are made up of thin imbricated sheets of small areal extent. Many

beds contain gypsum in small amounts, and thin lenses and seams of gypsum were observed at several localities. Stratigraphically below the strata included in Section I elongated lenses of limestone conglomerate and of limestone 3 inches to 4 feet in thickness become more abundant; and at the head of the tributaries to Rio Qquilque bands of limestone, limestone conglomerate, and gypsum are widely displayed. In places these rocks are represented by masses of white paste.

In the valley of the Rio Ayahuaycco the more calcareous portion of the Qquilque formation is represented in a section which contains the following strata:

II. Section of calcareous portion of Qquilque formation in a branch of Ayahuaycco Quebrada, about half a mile above its junction with Rio Qquilque.

Top.	Feet.
1. Shale, dark red, calcareous; with gypsum in seams and beds	30
2. Limestone conglomerate, composed of concretionary pellets, size of bird-shot	0.3
3. Limestone, calcareous or massive shale, brown, mottled with patches and bands of yellow; concretionary ..	6
4. Sandstone, yellow, highly calcareous, with shale partings	2
5. Limestone conglomerate, pellets from size of bird-shot to size of buckshot	2
6. Sandstone, banded green, yellow, and brown; thin-bedded	4
7. Shale, banded, and copper-green limestone; shale gypsiferous	12
8. Limestone, arenaceous, red-brown, in general massive, but full of gray limestone concretions; bands of gypsum and lenses of limestone conglomerate. This bed may not be in place	30
	<hr/> 86.3

The strata in this section have been disarranged by a number of small faults.

The nature of the rocks and the order of deposition indicated by Sections I and II are fairly typical for the entire Qquilque formation. In places, however, as at the head of the Huatanay, lenses of limestone conglomerate, separated only by thin layers of brown or gray sandstone, highly calcareous shale, or gray-blue massive limestone, are particularly abundant. In the bed of the Huatanay south of Sacsahuaman is a bed of con-

glomerate 20 feet thick consisting of limestone and gypsum balls, intersected by seams of gypsum. In places the sandstone of the Quilque formation is coarse grained or conglomeratic, and at a point three-fourths of a mile northeast of Ttica-Ttica Pass the upturned beds of sandstone contain pellets of shale, subangular pebbles of quartz exceeding half an inch in diameter, and angular fragments of scoriaceous basalt of much larger dimensions.

The age of the Quilque strata is unknown; their assignment to the Permian rests on imperfectly determined field relations. That these beds are continental rather than marine in origin is suggested by various features described above.

PACHATUCSA FORMATION.

The volcanic conglomerates and sandstones forming the heights of Pachatusa and Atascasa, on the northern rim of the Cuzco Valley, are grouped in the Pachatusa formation. The strata constitute part of the south limb of a giant anticline whose crest has been trenched by Urubamba River to a depth of nearly 6,000 feet. Sierra Pachatusa has thus been carved into a cuesta whose bluntly serrated crest, attaining a height of 15,915 feet, constitutes the commanding topographic feature of the bordering walls of the Cuzco Valley. From the summit of the cuesta the descent to the Urubamba is precipitous; toward the south a dip slope at an angle of 20° to 30°, gouged by ancient glaciers, extends for more than a mile (fig. 10).

In a broad sense the strata included in the Pachatusa formation may be classed as volcanic conglomerate. They exhibit, however, wide variations in amount, character, and distribution of the igneous constituents. In the Pachatusa hogback, where the tilted beds of dark-red conglomerate are 5 to 40 feet thick, the lowest strata examined are composed largely of quartz pebbles; the upper beds include angular and subangular fragments of quartz, sandstone, quartzite, basalt, and several varieties of dense basic rock embedded in a matrix of similar material. Six pebbles were collected in the field as representatives of different types of igneous rock. In color the specimens are brown, red, greenish, white, drab, and mottled; their textures range from scoriaceous through porphyritic to microcrystalline. When the pebbles were subjected to microscopic analyses, however, they were all found to belong to the andesite family. They consist of andesine as pheno-

crysts and as a constituent of the groundmass; brown hornblende, in many places resorbed; iron ore, chiefly magnetite, distributed as grains and also replacing biotite and hornblende; titanite and apatite in small quantity. Calcite, serpentine, chlorite, chalcedony, and quartz constitute the list of secondary minerals. One of the specimens collected proved to be an andesitic tuff, or tuffaceous sandstone. It consists of well-rounded grains of clear quartz, partly decomposed fragments of microcline and oligoclase, and lapilli of andesite, all firmly cemented by silica. In comparison with other fragments the chunks of andesite are large and angular and suggest contemporaneous igneous activity at no great distance.

In texture the individual strata of the Pachatusa formation vary widely and abruptly, both along the strike and in the direction of dip. No beds of fine ash were noted. Large blocks of lava are common and at one locality a mass of amygdaloidal andesite 80 feet long and 30 feet thick was observed. The size of these masses, their conformable relation to underlying beds, and the fact that vesicles on their surfaces as well as larger cavities and joints are occupied by sandstone suggest contemporaneous extrusions. It is not improbable that further study will reveal the presence of lava flows as persistent members of the stratigraphic series.

In the Atasccasa region the presence of igneous knobs and the wide variation in thickness and extent of the lenslike beds have produced a topography of hills and flats entirely unlike the Pachatusa cuesta. In this area the strata of the Pachatusa formation are cut by intrusions and their volcanic constituents are apparently nearer their source. Volcanic ash in beds and lenses 2 to 90 feet thick is interstratified with volcanic conglomerate and sandstone. Near the intrusive masses the arenaceous sediments have been converted into quartzite, and beds of volcanic breccia near one of the dikes are believed to indicate the site of an ancient vent which supplied at least part of the igneous fragments present. In addition to igneous fragments the conglomerate and ash beds at Atasccasa contain innumerable rounded and subangular quartz fragments as much as half an inch in diameter, also feldspars and blocks of sandstone, shale, and quartzite.

The Pachatusa beds are believed to be of continental origin, but their age is undetermined. The strata seem to underlie conformably the red sandstones and shales of the Huayllabamba formation at the edge of the overlying Ichchu-Oreco lava and

are assigned to the same system (p. 71). Several thousand feet of strata underlying the Pachatucsa beds, displayed in the wall of the Urubamba canyon, have not been studied.

HUAYLLABAMBA FORMATION.

Brown sandstone and chocolate-colored arenaceous shale are by far the most common rocks in the Cuzco Valley. They underlie the highlands south of the Huatanay and form the north side of the valley of that stream from Tticapata eastward to the Urubamba. The part of these widely extended arenaceous beds west of the Huancaro fault is included in the Qquilque formation;²⁴ for the remaining much larger part the term Huayllabamba formation is proposed.

In addition to the typical strata of brown sandstone and chocolate-colored shale which constitute about 90 per cent of the Huayllabamba formation, it contains gray sandstone and a few thin layers of black shale, gray shale and limestone. Along the highlands forming the divide between the Huatanay and the Apurimac drainage basins, gray and brown conglomerates are so abundant as to justify separate grouping: the Molle-Orcco conglomerate member. Throughout their extent the strata of the Huayllabamba formation are disturbed; a bewildering variety of normal and asymmetric folds are represented by truncated remnants and faults of small displacement may be numbered by hundreds. The trends of the axes of synclines and anticlines fall in general within the northwest quadrant, with an average for the more prominent folds of about N. 50°-60° W.; many fault planes strike in the same direction. There are, however, numerous exceptions to the general trend and a complete analysis of the stratigraphy involves traverses separated by distances of a mile or less.

In the time at my disposal I found it impossible to determine the limits of the Huayllabamba formation, but typical sections showing the character and arrangement of its strata were measured at a number of places both north and south of the Cuzco Valley axis.

Huayllabamba Formation north of Rio Huatanay.

III. Section of the Huayllabamba formation: north side of Angostura Narrows, beginning at the 13,000-foot contour line and extending S. 50° W. down the slope.

²⁴ See p. 55.

Strike N $70^{\circ} \pm$ W; dip S 30° - 40° . Measured with the assistance of K. C. Heald.

	Feet.
1. Sandstone, brown, massive, microscopically fine grained; gray quartz with ferric and calcareous cement	3
2. Shale, chocolate, arenaceous, irregularly bedded, calcareous, imbricated, nodular	6
3. Shale, chocolate, and calcareous sandstone, in alternating beds, 3 to 6 inches thick; contains thin lenses of gray quartz sandstone	25
4. Sandstone, brown	4
5. Concealed by debris	50
6. Sandstone, white quartz, medium grained; in three beds separated by layers of brown sandstone	6
7. Shale, chocolate	3
8. Sandstone, brown	6
9. Shale, chocolate, and sandstone, in about equal amounts; beds 2 to 6 feet thick; much broken . . .	40
10. Sandstone, brown, with small lenses of chocolate shale	6
11. Shale, chocolate, and sandstone, unevenly bedded, lenticular, imbricated	12
12. Sandstone, brown	5
13. Shale, chocolate, with bands of brown sandstone; sandstone cross-bedded; shale surfaces sun-baked, and traversed by mud cracks	14
14. Sandstone, brown	2
15. Shale, chocolate	4
16. Sandstone, brown	7
17. Shale, chocolate	2
18. Sandstone, brown	4
19. Shale, chocolate, with layers of brown sandstone . . .	6
20. Sandstone, gray, highly calcareous, with overlapping lenses of brown sandstone and chocolate shale; also pebbles of shale 1 inch in diameter	4
21. Shale, chocolate	3
22. Sandstone, gray, like No. 20	5
23. Shale, chocolate	1
24. Sandstone, brown to chocolate; very thin-bedded, tangentially cross-bedded, ripple marked; worm tubes; sun-baked surfaces specked with flakes of muscovite	12
25. Shale, chocolate, nodular, imbricated	5
26. Sandstone, banded, alternating paper-thin layers; surfaces coated with brown and black hematite	10
27. Shale, chocolate, calcareous	2
28. Sandstone, brown; on its uneven surface are plastered lumps of clay shale	4
29. Shale, chocolate, sandy and calcareous, unevenly bedded	3
30. Sandstone, brown, thin-bedded and banded like No. 26	9

	Feet.
31. Shale, chocolate	2
32. Sandstone, brown, thin-bedded, cross-bedded, ripple marked	11
33. Shale, chocolate, with lens of sandstone; footprints(?) on sun-dried surfaces	3
34. Sandstones, alternating gray and brown; with lenses, stringers and nodules of calcareous chocolate shale	14
35. Shale, chocolate	3
36. Sandstone, brown, with lenses of shale at top	10
37. Shale, chocolate	6
38. Sandstone, brown, extremely thin-bedded	3
39. Shales, chocolate	3
40. Sandstone, gray, with bands and lenses of chocolate shale	12
41. Shale, chocolate	2
42. Sandstone, gray, fine grained; contains chunks of shale and a few well-worn quartz pebbles	28
43. Shale, chocolate; upper surface highly uneven, channeled	2
44. Sandstone, brown, with 4 to 6 inch bands of chocolate shale	40
45. Sandstone, brown, and chocolate shale, in alternating beds 1 to 8 feet thick, with features essentially like Nos. 30-45 inclusive	300
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	703

Two hundred feet of rocks, exposed in scattered outcrops and stratigraphically above the beds included in Section III, differ from the measured strata only in having a somewhat more regular lamination and a slightly greater calcareous content. Two thin layers or lenses of black argillaceous limestone were noted. All the beds are thin, individual layers rarely exceeding 5 feet. The transition from shale upward into sandstone is in most places accomplished by means of a sandy zone made conglomeratic by the presence of fragments of the underlying shale. The shales themselves usually consist of alternating arenaceous and argillaceous layers one-sixteenth to 1 inch thick. Many of the arenaceous shale laminæ present smooth, glistening, sun-baked surfaces specked with mica, dotted with mud lumps, crossed by polygonal cracks. Features interpreted as worm trails and borings and impressions of plant fibers were noted at a few places. The beds are traversed by closely spaced joints which furnish the talus slopes with rhombohedral blocks a few inches in long diameter.

IV. Section of Huayllabamba formation on south branch of Rio Huaccoto.

Strike N 70° W; dip 40° S.

	Feet.
1. Shale, chocolate to dark red; friable	10
2. Sandstone, brown, with included fragments of chocolate shale	0.2
3. Shale, chocolate	0.2
4. Sandstone, brown	6
5. Shale, chocolate, with lenses of sandstone	7
6. Sandstone, brown	4
7. Shale, chocolate, with thin beds of sandstone	12
8. Sandstone, brown	3
9. Shale, chocolate	2.6
10. Sandstone, brown, with two 3-inch bands of chocolate shale	13
11. Shale, chocolate	4.5
12. Sandstone, brown	3
13. Shale, chocolate	1.5
14. Sandstone, brown; with 5-inch lens of chocolate shale	12
15. Shale, chocolate	2
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	81

The Huaccoto section is about 1,000 feet, stratigraphically, below the strata included in Section III. The distinction between sandstone and shale in this section is not well marked. All the shale beds are arenaceous, and the sandstone strata are laminated, rarely cross-bedded. Intermittent exposure to the sun is attested by mud cracks and films of glistening, compact mud which mark the division planes between laminae.

In a series of strata at Cerro Picol, whose position in the stratigraphic column is below the beds of Section IV, thin beds of dark-red arenaceous limestone were noted, and the chocolate-colored shales were found to be more calcareous than at the localities represented by Sections III and IV. Also, thin beds of gray sandstone, banded, minutely cross-bedded, and containing pebbles of gray shale, chocolate-colored shale, and red limestone, constitute about 15 per cent of the 700 feet of the strata examined.

At Ccorao Pass, at an elevation of 12,500 feet, thin bands of brown argillaceous limestone are interbedded with the familiar brown sandstones, chocolate-colored shales, and gray sandstones.

V. Section of Huayllabamba formation, Ccorao Pass between Seqqueray and Catunga-Huayna.

Strike N 80° W; dip 40° ± S.

	Feet.
1. Sandstone, brown to gray, fine grained, even grained, massive; composed of quartz with small amounts of feldspar and mica and specks of iron ore. Many shale pellets near upper surface. Forms cliff	20
2. Shale, dark red to chocolate; calcareous; sun-baked, includes beds and lenses of dark-red sandstone	30
3. Sandstone, brown, in part gray, with thin beds of shale; mostly fine grained, but includes beds with quartz grains the size of bird shot and pellets of chocolate-brown clay, foliation surfaces mud cracked	65
4. Sandstone, gray, fine grained, feldspathic	1
5. Limestone, dark red, or highly calcareous sandstone, in beds about 2 inches thick, including shale layers ...	5
6. Sandstone, brown, medium grain, even grained, slightly calcareous	6
	<hr/> 127

The strata in Section V are disturbed by numerous faults of small displacement. Green copper stain is common on slickenside surfaces. The chocolate-colored shales, abundant in Sections II and IV, are here relatively rare.

The lofty mass of Sencca, overlooking the Cuzco Basin from the northwest, consist essentially of strata of brown and gray sandstone interspersed with beds of chocolate-colored shale. Much of the sandstone is feldspathic and approaches arkose in composition and texture; many beds include irregular layers of conglomerate consisting of angular chunks of shale. The strata, particularly at the base of Sencca, are intricately fractured and where most disturbed are impregnated with malachite accompanied with lesser amounts of azurite.

In the bed of the Huatanay and along the Chunchullumayo, thin strata of black limestone and of black shale were found, and a measured section of the west bank of Rio Cachimayo, 2 miles above San Sebastian, includes 15 feet of black, slightly carbonaceous shale, in the midst of which are two layers, each half an inch thick, of nodular limestone. In other respects the rock in Cachimayo Valley is typical for the Huayllabamba formation.

Huayllabamba Formation south of Rio Huatanay.

On the south side of the Cuzco Valley, beds assigned to the Huayllabamba formation were studied at several localities. The rocks forming the deeply carved slopes bordering the Huatanay east of Rio Huancaro are brown sandstone and chocolate-colored shales which differ in no essential particular from the strata of the Huayllabamba formation previously described. On the highlands south of Saylla few of the alternating beds of arenaceous shale and fine-grained brown sandstone exceed 1 foot in thickness on the lower north slopes. Above 11,500 feet the strata thicken, and the ragged serrate crest of Maho-Pinta, at about 13,500 feet, consists of beds of sandstone in nearly vertical position, 4 to 20 feet in thickness. Between the sinuous rows of teeth are trenchlike passages resulting from the erosion of the less resistant shale. One mile farther south the tiny streams forming the headwaters of Rio Kkaira follow the strike of shale beds and are inclosed between unevenly spaced walls of brown and gray sandstone 20 to 80 feet in height. Approximately 80 per cent of the sandstone between the Huatanay and Rio Uspha is brown in tone and fine to medium in texture. Gray sandstone is irregularly distributed and in common with the more abundant brown rock contains lenses of conglomerate consisting of fragments of chocolate, red, rarely green clay shales. At a point on the middle course of Rio Huanacauri several beds of gray and pink limestone, of small extent but sufficiently thick for quarrying, were noted among the prevailing arenaceous strata. At a number of localities the surfaces of shale and of thin sandstone beds are sun-baked and cracked and exhibit other features indicative of intermittent exposure to the atmosphere.

Molle-Orcco conglomerate member.—On the highlands forming the divide between the Huatanay and the Apurimac drainage basins the typical sandstones and shales of the Huayllabamba formation grade upward into a series of beds including many strata of a coarse conglomerate. This phase of the formation is well displayed at Molle-Orcco. The conglomerate beds, involved in a series of intricate folds, form many high ridges and have determined the courses of the smaller streams. Where in vertical position they rise above the surface as a series of parallel dikes, producing an extremely rough topography (fig. 34).

The proportion of conglomerate to sandstone in the Molle-Orcco member is variable. At Ccochacolla a succession of

conglomerate beds is interrupted by insignificant amounts of finer-grained material; at certain other localities the conglomerate strata are widely spaced. In places beds a few feet thick consisting chiefly of pebbles exceeding 1 inch in diameter may be traced continuously for more than a mile; elsewhere the conglomerate is displayed as lenses 3 to 10 feet thick and a few

FIG. 34.



FIG. 34. Molle-Orcco conglomerate in vertical position at Molle-Orcco.

hundreds of feet long. At some localities the conglomerate forms merely a patch 3 to 6 inches thick overlying gray or brown sandstone. Individual pebbles 2 to 3 inches in diameter occupying isolated positions in several cubic feet of sandstone, as well as strings of pebbles entirely detached from their neighbors, are not uncommon.

The Huayllabamba formation, including the Molle-Orcco conglomerate, is well displayed for study on the Cuzco-Ayus-bamba trail leading up the Huancaro Valley (fig. 35).

VI. Section of Huayllabamba formation, including the Molle-Orcco conglomerate member, on west bank of Rio Huancaro below the mouth of Rio Chchocco.

Northeast limb of syncline. Strike $N\ 80^{\circ} \pm W$; dip $90^{\circ}-10^{\circ}\ S$.

Feet.

1. Sandstone, gray on surface, gray-brown below, and conglomerate, cross-bedded, in places banded with black sand. Conglomerate constitutes about 30 per cent of bed and is arranged in lenses 10 to 100 feet long, 1 inch to 4 feet wide, in irregular masses 3 to 6 feet in diameter, and as isolated strings of pebbles;

FIG. 35.



FIG. 35. General view of strata comprising the Huayllabamba formation, including beds of the Molle-Orcco conglomerate member. Ayusbamba trail.

- | | |
|--|----|
| pebbles reach a maximum size of 8 inches and average about 1 inch; types noted include quartz of various colors, feldspar, biotite granite, porphyritic trachyte, diabase, green, yellow, and brown quartzite; hornstone, slate, brown sandstone, brown shale, and limestone. The pebbles are fairly well worn and rounded and are embedded in sand held together by ferric, argillaceous, and calcareous cement | 30 |
| 2. Sandstone, dark red, friable, calcareous | 3 |
| 3. Sandstone and conglomerate like No. 1, except for abundant flat pebbles of dark-red sandstone and shale | 8 |

	Feet.
4. Sandstone and conglomerate like No. 1, thin-bedded	3
5. Sandstone, brown, with pebbles of clay shale	2
6. Shale, chocolate colored, arenaceous, and thin-bedded calcareous sandstone	5
7. Sandstone, brown, with lenses of red calcareous shaly sandstone	9
8. Conglomerate, gray	2
9. Sandstone, red, calcareous, friable, shaly	5
10. Alternate layers of sandstone like Nos. 9 and 7, and lenses of pink-gray limestone a fraction of an inch in thickness.	15
11. Sandstone, gray-brown, with few lenses of conglomerate	4
12. Sandstone, dark red, shaly, highly calcareous	4
13. Sandstone, gray-brown	4
14. Sandstone, dark red, shaly	5
15. Alternating bands of sandstone like Nos. 12 and 13	13
16. Sandstone, gray to brown, conglomeratic in places and containing lenses and narrow, more or less continuous bands of sandstone like Nos. 12 and 13	110
17. Sandstone, red, calcareous, friable	5
18. Sandstone, brown and gray, and chocolate-colored shale, in beds and lenses 6 inches to 4 feet in thickness. Sandstone has calcareous cement; red shaly beds vary in composition from calcareous sandstone through argillaceous calcareous shale to pure limestone. Foliation surfaces sun-baked, rare ripple marks	305
19. Sandstone, dark red, highly calcareous, fine grained; quarried for building stone	6
20. Sandstone, gray, conglomeratic; abundant brown, flat pebbles of shale	27
21. Sandstone, brown, calcareous, with limestone lenses	9
22. Conglomerate, gray, with pebbles of brown sandstone and shale	10
23. Sandstone, brown, calcareous	5
24. Sandstone, gray and brown; with beds and lenses of conglomerate like No. 1 and many fragments of brown clay shale	55
25. Concealed by débris; probably brown shaly sandstone	100
26. Sandstone, brown and gray, with layers of abundant brown shale pebbles; strike N. 80° E.; dip 40° SW.	60
27. Beds 3 inches to 6 feet thick, of gray sandstone, with rare conglomerate pebbles; brown sandstone, with many brown shale pebbles; red to chocolate calcareous shale and shaly sandstone; beds of limestone one half inch and less in thickness. Shaly parts of sandstone beds sun-baked and mud cracked	90

	Feet.
28. Sandstone, gray, coarse, with very thin bands of red calcareous shaly sandstone. Few pebbles except of brown shale	14
29. Limestone layer in chocolate shale; upper surface sun-baked and marked by mud cracks, worm tracks and footprints (?)	0.5
30. Sandstone, brown, thin-bedded, cross-bedded	5
31. Limestone, thin-bedded, shaly, arenaceous; surface of separate layers strewn with fine micaceous sand; sun-dried, sun-cracked; shows footprints (?)	1
32. Sandstone, gray, with thin beds of shale and shaly limestone	14
33. Shale, chocolate, sandy, with mud cracks, baked surfaces, tracks, etc. Strike N. 70°-80° E.; dip 30° S. Open joints, producing waterfall, trend N. 20° W. and E.; both sets nearly vertical	6
34. Sandstone, gray, with interbedded brown and chocolate calcareous shaly sandstone and thin limestone	30
35. Concealed by gravel	180
36. Sandstone, brown, and chocolate shale in alternating beds; dip nearly horizontal	45
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	1208.5

On the divide between the headwaters of the Chchocco and Llayllicasa, branches of the Huancaro, where the Molle-Orcco conglomerate is involved in a knot of twisted folds, the following section, typical for the area southwest of the Huancaro, was measured:

VII. Section of Molle-Orcco conglomerate member of the Huayllabamba formation near the head of Rio Chchocco.

Strike N 20° W; dip 80° SW.

	Feet.
1. Sandstone, gray and brown, and conglomerate; pebbles irregularly distributed	20
2. Shale, chocolate-brown, with layers of sandstone	3
3. Sandstone, brown, calcareous cement, cross-bedded; lenses of clay pebbles and of conglomerate	20
4. Shale and shaly sandstone, chocolate, calcareous	4
5. Conglomerate and coarse sandstone, brown; subangular and rounded pebbles as much as 1 foot in diameter of red and gray quartz, feldspar, sandstone, shale, limestone, granite and diorite, and slate	16
6. Shale, chocolate, arenaceous	6

Origin and Age of the Huayllabamba Formation.

The source of the materials composing the strata of the Huayllabamba formation is unknown. The terranes whose disintegration gave rise to the sediments were doubtless pre-vaillingly siliceous and must have included metamorphic rocks and a variety of igneous intrusives. Many features of the sediments indicate deposition by streams of fluctuating flow. The prevailing red color of the beds and the presence of slightly altered feldspars suggest an arid climate. On the evidence derived from field observation a large part at least of the Huayllabamba formation is believed to be of continental rather than marine origin. It is interesting to note that in general appearance as well as in several detailed features of composition and structure the Huayllabamba strata are not unlike the Newark sediments of Connecticut and New Jersey. No fossils other than impressions of plant fibers and doubtful footprints of a small animal of the dinosaur type were found in the Huayllabamba beds. The age of the strata is therefore unknown. They underlie the Yucay limestone (Upper (?) Cretaceous) and are unlike the richly fossiliferous Carboniferous (Pennsylvanian) strata of the Titicaca region.²⁵ The formation may be Permian, Triassic, or Jurassic, or it may include strata from more than one Mesozoic system. In the present report the Huayllabamba formation, including the Molle-Orco conglomerate, is assigned tentatively to the Jura-Trias.

YUCAY FORMATION.

The plateau surface north of the city of Cuzco and including the Yucay, Pucro, Kkallachaca, and Era pampas is developed on limestone. The plateau is sharply bounded on the south by steep cliffs facing Rio Huatanay; on the northwest, north, and northeast the sandstone rim of Sencca continued through Fortaleza and Sequeray forms the bordering wall. The topography of the pampa surface is subdued; rounded knobs separated by basin-like valleys are typical features (fig. 13). Sink-holes are common, and at one point part of the roof of an underground channel remains as a natural bridge. The rock forming the plateau is typically developed on the Yucay Pampa, and Yucay appears therefore to be a suitable name for the calcareous beds of this area.

²⁵ Gregory: Geologic sketch of Titicaca Island and adjoining areas. This Journal, xxxvi, pp. 187-213, 1913.

The Yucay formation consists of limestone of two types—(1) a black to gray massive variety, firm and compact, breaking with conchoidal fracture; (2) a drab-gray, thin-bedded, slightly arenaceous rock. The massive variety constitutes the bulk of the formation; the laminated type occurs in masses of small dimensions. Both types of rock develop light-gray tones on weathering and both are sparingly fossiliferous. The strata are traversed by joints and much broken by normal and thrust faults of a few inches to a few feet displacement;

FIG. 36.



FIG. 36. Typical exposure of Yucay limestone, Kkallachaca Pampa.

slickensided surfaces are common. An exposed ledge reveals brecciation carried to an extreme; even a hand specimen may consist of 10 to 15 angular fragments firmly re-cemented. The entire Yucay formation may be described as consisting of finely brecciated limestone broken into joint and fault blocks which in turn form knobs and ridges tilted at various angles and in nearly every direction. The rock outcrops are not unlike the broken surface of a lava flow (fig. 36).

Under such conditions measurements of strikes and dips have only local value and the determination of the attitude of the formation as a whole was found impossible in the time at my disposal. Moreover the intricate faulting of the sandstone beds inclosing the limestone has obscured the relations between the Yucay formation and the Huayllabamba forma-

tion. West of Fortaleza laminated limestone appears to overlie conformably the brown Huayllabamba sandstones; at two other points a hiatus is indicated by diverse dips and irregular contacts; and at two localities areas of Huayllabamba strata in normal attitude protrude through the limestone beds.

Fossils of marine habitat collected at three localities were studied by Dr. T. W. Stanton, of the United States Geological Survey, who submits the following report:

"I have examined your small collection of fossils from the limestones near Cuzco, Peru. The collection is in five lots with distinctive labels but the preliminary examination made it evident that the lots include only one fauna and probably came from a single horizon, as you had determined from the field relations. At least two of the species—a *Pecten* and a *Cucullaea*—occur in all five lots, the same naticoid shell in four of them and a *Cardita* in three.

It has not been possible to make specific determinations, partly because the fossils are not very well preserved and partly, and more especially, because the collections which have been described from South America are so meager in both number and size, and the localities from which they came are so widely scattered over the continent, that it would be accidental if any of the described forms should be found in a collection from a new locality like this one from Cuzco. The fossils include only echinoids, pelecypods, and gastropods. The entire absence of cephalopods in a collection believed to be of Cretaceous age is noteworthy. The basis of the opinion concerning age may be best indicated by the following briefly annotated list of the forms best recognized. In addition to those listed there are several specimens too imperfectly preserved for even generic identification.

Diplopodia? *sp.* A single imperfectly preserved specimen of a regular echinoid doubtfully referred to *Diplopodia*. It may be a *Cyphosoma*.

Hemiaster? *sp.* This irregular echinoid is also represented by a single specimen which shows the form fairly well but does not possess all the essential details of the sculpture and the apical disk.

Ostrea? *sp.* A small simple oval form represented by only two or three specimens.

Pecten *sp.* The collection contains at least two species of *Pecten* belonging to the group often called *Vola* or *Neithea* which Fischer, Dall and others consider the typical section of *Pecten*. Several species of this group have been described from the Lias of South America but none of them is identical with any of the present forms from Cuzco, which are more like Cretaceous types of the genus so far as may be judged from such imperfect specimens.

Avicula sp. A small simple form resembling *A. linguiformis*.

Cucullaea sp. A small, rather short form without distinctive sculpture.

Cardita sp. A strongly sculptured form not exceeding an inch in height or length.

Pleuromya sp. A single small specimen apparently belonging to this genus.

Natica? sp. Several casts of small stout naticoid shells which may include more than one species and possibly more than one genus.

Turritella? sp. Two very small casts which do not retain the sculpture.

Fasciolaria? sp. A single specimen doubtfully referred to this genus on account of form and sculpture.

Cinulia? sp. An imperfect cast and an imprint of part of the surface.

There can be little doubt that these fossils are Mesozoic and probably not older than Cretaceous. In the absence of Ammonites and other characteristic types for closer age determinations it would be imprudent to assign them to a definite horizon, though I think it most likely that they belong to the Upper Cretaceous."

Limestones of identical character and containing fossils of the same age remain as patches on the Fortaleza, Catunga, and Machu highlands and are exposed in thick beds near Ayus-bamba, on Apurimac River 15 miles south of Cuzco, as well as at points farther west. The preservation of remnants of once widespread Upper (?) Cretaceous limestone is believed to have resulted from the development of downsunken fault blocks.

The Yucay limestone is extensively used in construction for walls, foundations, pavements, and also in chiseled blocks for buildings. The famous Inca fortress of Sacsahuaman is built of enormous blocks of Yucay limestone brought from a quarry about 1 mile distant.

BAMBANUSA FORMATION.

The sandstones exposed along the eastern edge of the Bambanusa Pampa north of Ccasa-Cancha constitute the Bambanusa formation. Typical outcrops south of the Ichchu-Orcco lava field are white or light gray in tone; the unweathered rock is, however, in many places pink in color. Pure quartz sandstone with sugary texture is the predominant rock type, and its constituent grains are so feebly held together by cement that the rock crumbles under a blow of the hammer and piles of clean quartz sand are found at the base of cliffs. Erosion favored

by this easy disintegration has produced pinnacles and columns and bizarre forms which have no counterpart in the erosion remnants of other formations in the Cuzco region (fig. 37). At all places visited the rock is traversed by joints along many of which movement has taken place, as is indicated

FIG. 37.



FIG. 37. Erosion column formed of Bambanusa sandstone.

by slickensides and by numerous faults of a few inches displacement. The rock does not, however, show the crushing and shattering so common to the older sandstone of this district. The material filling the joints, even where calcareous, is more resistant to erosion than the rock itself, and the position of joints and faults is indicated by ridges rather than by depressions.

VIII-A. Section of the Bambanusa formation 1 mile north of Ccasa-Cancha.

Strike N 30° W; dip 8° NE.

	Feet.
1. Sandstone, massive pink to white, even grained, consisting of uniform fine grains of clear quartz loosely cemented by calcite. Elaborately cross-bedded by inconspicuous lines. Forms towers and hoodoos ...	20
2. Sandstone, thin-bedded; banded pink, light red, and gray; in places merely overlapping flakes; quartz grains, calcareous cement. Includes layers of arenaceous limestone	60
	<hr/> 80

VIII-B. Section of Bambanusa formation half a mile west of Section VIII-A.

Strike N 25°± W; dip 6° E.

	Feet.
1. Sandstone, pink to gray in tone, massive, fine grained, cross-bedded; white and pink quartz; calcareous cement	15
2. Shale, argillaceous and arenaceous; in beds the thickness of paper	1
3. Sandstone, pink; well-rounded grains of quartz, microscopic size; calcareous cement; cross-bedded and highly lenticular	6
4. Sandstone, dark red; quartz grains very fine; calcareous cement. Arranged as irregular lumps and lenses; one lens consists of white quartz and chert pebbles ranging in size from that of a pea to that of a small hickory nut	4
	<hr/> 26

The Bambanusa beds dip at a low angle and in a direction opposite to those of the bordering Pachatusa formation as well as of the underlying Huayllabamba sandstones. This unconformable relation is well shown at the head of the Chchiraura Canyon, where the eroded edges of brown sandstone strata, tilted south at an angle of 40°, are covered by pink-white beds with a northward inclination of about 35°.

The strata on the Urubamba divide between Pachatusa and Atasccasa are for the present grouped with the Bambanusa formation. The series consists of coarse sandstones and conglomerates in massive beds, 4 to 40 feet thick. On weathered

surfaces the rock is white to gray in color; pink tones resulting from the presence of pink quartz fragments and a small amount of ferric cement characterize the fresh rock. Portions of the ledges studied are fine-grained, but the typical sandstone members are coarse and gritty and consist of subangular, clear quartzes and fragments of decomposing feldspar. The conglomeratic phases are displayed as thin lenses or narrow stringers and consist of partly rounded, usually elongated pebbles of quartz, quartzite, and sandstone, rare igneous fragments, pellets and slabs of shale, and crystals of feldspar which retain their original form. The pebbles range from a fraction of an inch to over 2 inches in diameter and are arranged without evident sorting. The rock as a whole is firmly cemented with silica and iron, some parts in fact being developed as a glistening pink quartzite. The strata are highly cross-bedded, a structural feature exhibited both by curved bands and straight lines in the sandstone members and even more markedly by lenses and beds of conglomerate and coarse sandstone 6 to 10 feet in thickness. Unlike the Bambanusa sandstones south of Ichchu-Orcco, the beds on the divide, doubtfully assigned to this formation, dip southwest, in harmony with the strata of the Pachatusa formation. A continental origin for the Bambanusa formation is suggested by the structural features already described, but the geologic period during which the depositing streams were active is not known. Superficially the formation appears to be geologically young, perhaps early or middle Tertiary, and the field relations suggest that its component strata were laid down as sands and gravels in a basin developed by warping or faulting of the underlying older strata. On the other hand the absence of the Yucay limestone (Upper (?) Cretaceous) from the area south and east of Cerro Picol may indicate that parts of the Bambanusa formation are contemporaneous with the Pachatusa and Huayllabamba formations, assigned to the Jura-Trias (?).

SEDIMENTARY ROCKS NEAR THE MOUTH OF THE HUATANAY.

The sedimentary rocks of the lower Cuzco Valley were not mapped; they may belong with the Huayllabamba formation. The following notes were made during a rapid traverse from Sierra-Bella to Huacarpay.

The banks of the Huatanay at its junction with the Urubamba are formed of beds of resistant brown sandstone, 4 inches to 1 foot in thickness, interstratified with chocolate-red

shale. The beds, broken by faults and intruded by basic rock, strike west to N. 70° W. and dip to the south at angles of 30° to 40° . The bedding planes of both shale and sandstone present firm, glistening surfaces traversed by mud cracks, ripple marks, and worm trails (?) and are dotted with irregularly shaped fragments of mud shale. For a distance of about a mile south of Huambutio station, partly decomposed strata of limestone and gypsum in approximately horizontal attitude replace sandstone and shale. The limestone is blue-gray or banded with brown, and both massive and laminated beds are present. The gypsum, which is dark blue and white in color, is displayed as lenses and furnishes elaborately carved oblong and cubical blocks of the talus. A large part at least of the gypsum is secondary in origin and occupies joints in the limestone.

The canyon of the Urubamba along the railroad between Sierra-Bella and Cay-cay is cut in brown sandstone interbedded with shale and lenses of conglomerate composed of imperfectly rounded pebbles of quartz, sandstone, and bright-red shale.

SAN SEBASTIAN FORMATION.

The Cuzco Basin northward from Angostura Narrows is inclosed by a low interrupted wall of poorly consolidated sediments. These beds are well displayed both north and south of the village of San Sebastian, from which the name of the formation is derived. On the south side of the valley eastward from the mouth of the Huancaro the strata of the San Sebastian formation are practically horizontal and form conspicuous white banded cliffs along Rio Huatanay (fig. 32); along the northern rim, in the vicinity of San Sebastian, the strata dip gently to the south and merge with the alluvium of the main valley floor. The sediments include sand, limestone, peat, and adobe, with small amounts of gravel, and were deposited within and on the immediate shores of ancient Lake Morkill.²⁶ The nature of these lacustrine deposits is shown in the following typical sections:

IX. Section of San Sebastian formation on Rio Huancaro near its junction with the Huatanay.

²⁶ See p. 34.

Strata horizontal.

	Feet.
1. Adobe and fine sand forming present surface	3
2. Sand, white, calcareous	1
3. Adobe, yellowish	2
4. Limestone, white, compact, massive in places, elsewhere very thinly laminated; abundant shells of <i>Physa</i> , <i>Sphærium</i> , and <i>Planorbis</i> ; roots represented by rusty tubes; quarried for lime	6
5. Adobe with lenses of white lime; several overlapping lenses of gravel, pebbles as much as one half inch in diameter of quartz, sandstone, and aggregates of black sand	9
6. Sand and adobe like No. 12	2
7. Limestone, white, fossiliferous	0.5
8. Adobe and sand like No. 12	10
9. Limestone, white, with carbonized material in 1-inch bands, lens-shaped; capped by yellow weathered zone	1
10. Adobe, light red, in very thin beds; exceedingly irreg- ular and wavy in deposition and containing lenses 3 to 5 feet thick of fine sand and fine gravel with pebbles of quartz and lime concretions as large as buckshot, all very well worn; contains also minute streaks of white lime and of carbonized materials ..	5
11. Shale-like materials, black, in bands 2± inches thick, consisting of (1) white weathered adobe at base; (2) gray shale with abundant impressions of grass, stems, roots, etc., and rare shells; and (3) thin beds of black peat. These beds are continuous, but portions of 1, 2, and 3 interleave at distances of 20 to 100 feet	3
12. Adobe consisting of fine sand with clay; highly cal- careous; lime in minute specks and streaks; rare coarser-grained material of same composition in lenses	18
	<hr/> 61.5

This section is shown in fig. 38.

X. Section of San Sebastian formation on bank of Rio Huatanay, half a mile south of San Sebastian.

Beds horizontal.

	Feet.
1. Adobe, massive, brown, firmly cemented; traversed by vertical root tubes; contains scattering grains of sand the size of buckshot in lower part. Toward top color gradually changes to yellow-gray	5

	Feet.
2. Limestone, white, massive; abundant shells; a calcareous, consolidated mud silt	5
3. Shales or mud, white, yellow, black and brown; thin-banded; calcareous, unconsolidated; becoming more arenaceous and more carbonaceous in middle	4
4. Limestone, like No. 2	6
5. Adobe like No. 1, separated from No. 4 by an erosional unconformity	10

FIG. 38.

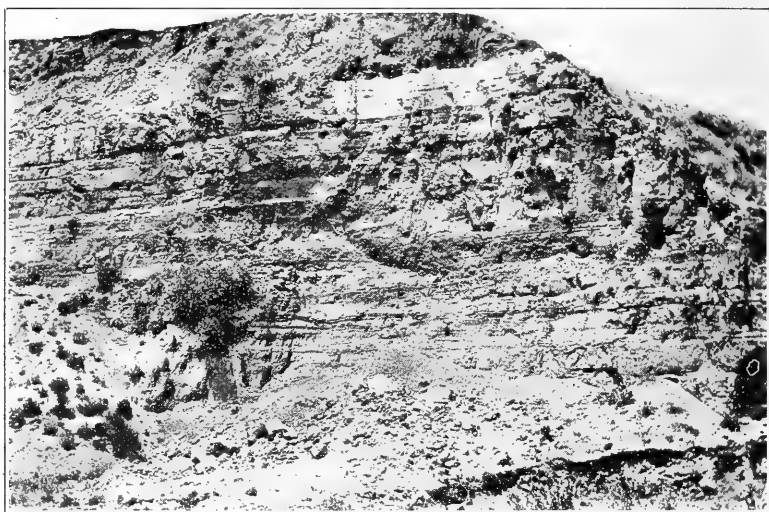


FIG. 38. Section of San Sebastian formation near the mouth of Rio Huancaro.

6. Sand, gray to black, coarse, cross-bedded, thinly stratified, with bands of fine brown sand	2
7. Sand and clay in alternating dark-red and gray regular beds, 1 inch to 1 foot in thickness; sand fine with few coarse beds; clay and adobe increase in amount toward top; forms vertical banks of river	55

At the mouth of Rio Huilcarpay, 800 feet east of the locality including the strata of Section X, the laminæ of adobe unconformably overlie and are interleaved with lenses of fine and coarse cross-bedded black sands and gravels. Thin beds of decomposed peat are also present.

XI. Section of San Sebastian formation half a mile south of San Geronimo railroad station.

Dip 0 to 2° North.

	Feet.
1. Sand, fine, and scattered cross-bedded lenses of gravel overlain by gravel and boulders forming the surface of a fan	40
2. Limestone, white, very thin-bedded, containing abundant shells; also impressions of plants in one adobe-like band; bed persistent and cut by a number of quebradas in this vicinity	2
3. Gravel lens; pebbles of sandstone, subangular, as much as 2 inches in diameter; partly cemented	1
4. Sand, fine, and adobe in alternating very thin beds	55
5. Clay, drab, highly calcareous, containing plant roots, and shells	0.3
6. Sand, fine, compact, quartz; beds a fraction of an inch thick, with rare lenses of coarse sand and beds of hard calcareous adobe 4 inches to 1 foot in thickness. Beds of adobe project as shelves on quebrada walls	70
	<hr/> 168.3

The area of sands, limestone, and adobe about half a square mile in extent, forming the flats south of San Geronimo at elevations between 10,650 and 11,000 feet, may be considered part of a slope included in the coast and under-water shore of ancient Lake Morkill, now much dissected. The slope of the rock-surface valley side on which the materials were deposited is about 20°.

Near the west end of ancient Lake Morkill, where the gentle shore slopes were alternately flooded and exposed in response to fluctuating volume of lake water, a number of sections were measured. A characteristic exposure is shown in fig. 39, and the following section is considered typical for this locality:

XII. Section of San Sebastian formation in Chunchullumayo quebrada, near junction with Rio Huatanay.

Dip about ¼° East.

	Feet.
1. Soil of adobe, dark red	2
2. Limestone, white, thin-bedded; shells abundant	2
3. Gravel, coarse and fine, well stratified; pebbles 2 to 3 inches in diameter, rarely larger	5
Unconformity.	

	Feet.
4. Adobe, dark red, massive, highly calcareous, with lenses of fine and of coarse gravel; abundant vertical root tubes and rare shells	6
Unconformity.	

FIG. 39.

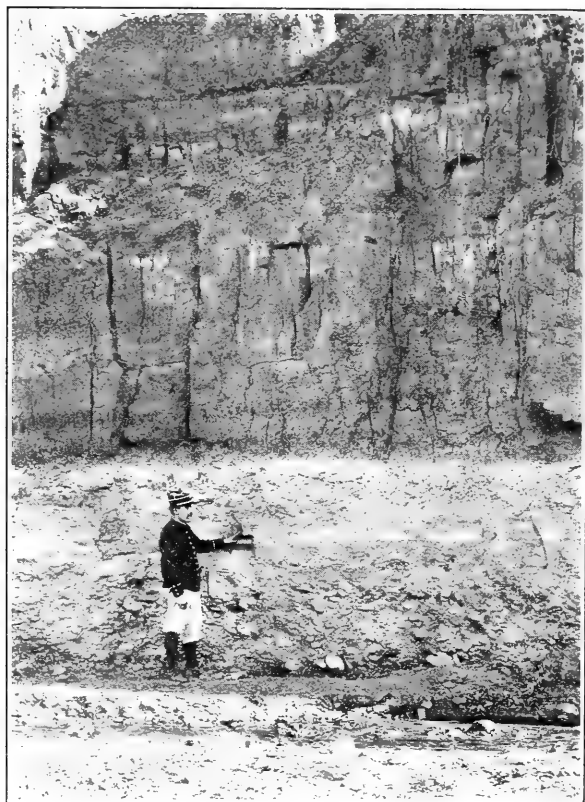


FIG. 39. Section of San Sebastian formation near the Cuzco railway station. Contains adobe sand, fossiliferous limestone and gravel. Hiram Bingham, photo.

5. Sand, fine, yellow at top; with gravel of flat fragments; upper surface channeled; vertical root tubes; rare shells	4
6. Adobe, dark red, massive, firm, calcareous; with small lenses and masses of fine gravel	10
Unconformity.	

	Feet.
7. Silt, earthy, calcareous, compact, banded with white layers representing old soils; few shells	7
Unconformity.	
8. Sand and coarse gravel composed of angular fragments of sandstone	4
	<hr/> 44

In quebradas immediately north of the village of San Sebastian over 200 feet of sediments assigned to the San Sebastian formation are exposed. At their contact with the Yucay limestone the beds are nearly horizontal; farther southwest they slope toward the Huatanay with a dip gradually increasing to 15° (fig. 31). In this locality the lacustrine beds are chiefly sand (fig. 40); limestone and adobe being comparatively small in amount, as shown in the following partial section:

XIII. Section of San Sebastian formation in wall of unnamed quebrada 1 mile north of San Sebastian Cathedral.

Strike N; dip 6° W.

	Feet.
1. Limestone forming surface slope; thin-bedded, soft, porous, chalky; contains shells	12
2. Sand, hard-packed; alternating fine and coarse; lenticular, cross-bedded	30
3. Limestone, thin-bedded, impure	5
4. Adobe with abundant plant impressions	2
5. Sand	16
6. Adobe	3
7. Sand like No. 2	60
8. Sand, fine, and adobe with 3-inch band of white limestone	16
9. Gravel, with pebbles as much as 2 inches in diameter	1
10. Gravel, fine, and coarse sand, dark gray, with thin beds of fine light-red sand; cross-bedded and intricately faulted along planes showing displacement of individual blocks of one half inch to 8 inches	25
11. Sand, even grained, fine, cross-bedded; faulted	20
12. Limestone, white	3
13. Sand	2
	<hr/> 95

In the sediments at San Sebastian the calcareous beds are highly variable in thickness and extent; in certain places examined only one thin bed of limestone was found in 100 feet

of strata; elsewhere three or four strata are included in 25 feet of sands. On a hill 1 mile east of the village, where 150 feet of bedded sands were exposed, no limestone was seen. Car-

FIG. 40.

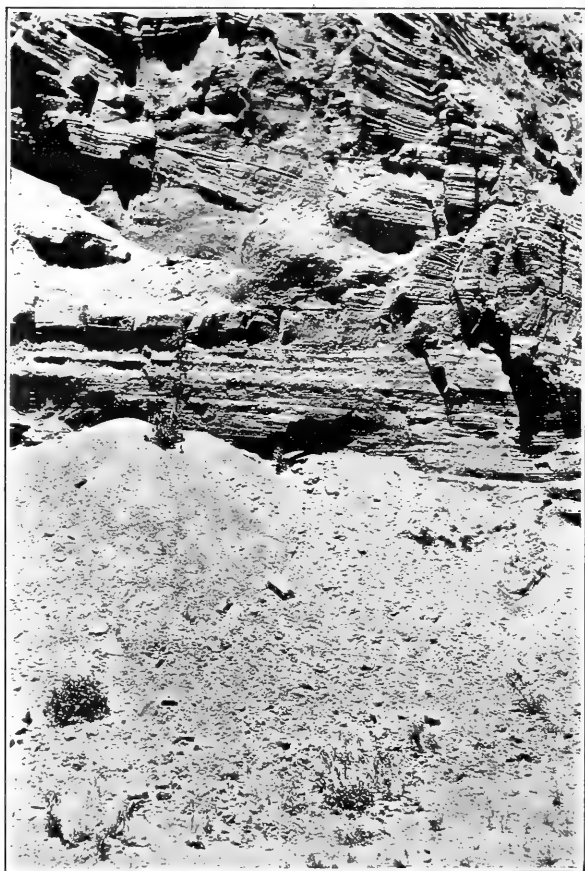


FIG. 40. Faulted and cross-bedded strata of fine sand, San Sebastian formation, about $1\frac{1}{2}$ miles north of San Sebastian cathedral.

bonaceous material is rare in the sharply cut quebradas north of San Sebastian, but at one point along the highway lignitic peat occurs in abundance and has led to unsuccessful mining.

Origin and Age of the San Sebastian Formation.

Strata of sand and of "tripolite" at various localities in the Department of Cuzco, probably including San Sebastian, were noted by Dueñas,²⁷ who offers two hypotheses to account for their presence—(1) that the ocean of Tertiary time covered the Andes Mountains; (2) that Lake Titicaca formerly extended northwestward into the Apurimac and Urubamba valleys—an assumption which appeared to Dueñas as the more probable. The San Sebastian beds are, however, local deposits, and their composition and stratigraphic arrangement indicate lacustrine origin. Quiet, fresh water is required for the deposition of pure-white limestone containing abundant shells of *Physa*, *Sphærium*, and *Planorbis*. Some of the clay beds also demand quiet water for their accumulation, and the long root tubes in the compact silt and adobe, as well as impressions of reeds and layers of earthy lignite, suggest shores or delta flats. Lenses of gravel, channeled beds, and ancient soils indicate that the lake was playa-like in character, or at least suffered fluctuations in volume sufficient to expose and cover the shore slopes alternately. Fossils occur in abundance, and it is keenly disappointing to learn from Dr. Dall and Professor Schuchert, who kindly examined my collections, that the shells belong to species which range from the Jura to the present. The plant fragments, also, are unfortunately not diagnostic. In the absence of paleontologic evidence the age must be determined by the less direct methods of physiography. The problem is to interpret the relations existing between the lacustrine deposits and the glacial gravels of the Cuzco region. On the basis of such study the San Sebastian formation is assigned to late Pliocene or early Pleistocene time. This conclusion is fairly satisfactory from the physiographer's standpoint and conflicts in no way with the paleontologic evidence.

It may be noted that the age of the San Sebastian beds is the same as that assigned to the deposits at Ayusbamba, where vertebrate fossils were obtained.²⁸

PLEISTOCENE AND RECENT FORMATIONS.

Deposits of glacial origin, including moraines, gravel fans, and lacustrine sediments, are widely distributed within and on the borders of the Cuzco Valley. These are discussed under

²⁷ Op. cit., p. 24.

²⁸ Eaton, G. F., Vertebrate fossils from Ayusbamba, Peru, this Journal, xxxvii, pp. 141-154, 1914.

a separate heading.^{28a} Post-Pleistocene or Recent formations include gravel and sand plains resulting from the erosion of glacial gravels and the late readjustment of stream channels as the result of natural and artificial processes. Travertine is found along nearly all drainage channels crossing the Yucay limestone. At many waterfalls and rapids the lime of the highly charged water is deposited on reeds and various grasses, preserving their forms in great detail. On the west branch of Rio Sebolla-Huaycco, about half a mile above its mouth, the stream is bordered by a cliff 40 feet in height composed entirely of lime-incrusted plants of species identical with those which constitute the harsh, stunted vegetation of the present day. At other places casts of plants ground up and dissolved by running water are redeposited as beds of banded gray travertine containing minute fragments of leaves, branches, and fibers.

IV. THE IGNEOUS ROCKS.

INTRODUCTION.

The igneous origin of two rock masses in the Cuzco Valley, El Rodadero and Rumiccolca, has long been recognized, but the indiscriminate use of the terms "amphibolic rock," "basaltic rock," "trachyte," "granite," "sienite," and "porphyry" renders most of the published descriptions of little use for geologic purposes. Microscopic analyses by Dueñas²⁹ of specimens from El Rodadero and from Huaccoto mark the beginning of systematic petrographic studies in this part of Peru. During the course of the field season of 1912 most of the exposures of igneous rock within the Cuzco Valley were visited, and it is believed that the geologic map combined with the petrographic notes gives a fairly complete description of their distribution and character.

Extrusive masses are typically represented by the volcanoes at Huaccoto and Rumiccolca; intrusives by El Rodadero and the outcrops at Chchiraura; and elastic volcanic materials may be studied on the slopes of Cerro Pachatusca.

Volcanic activity in the Cuzco Valley has been local and relatively feeble. The exposures of igneous rock, both intrusive and extrusive, are small, the largest (Rumiccolca) covering an area of less than 2 square miles. Except at Atascasa the original masses have suffered little from erosion.

^{28a} See p. 39.

²⁹ *Op. cit.*, pp. 178, 192, 1907.

The rocks are prevailing basic in composition. Specimens assigned to the syenite family were collected at two localities; varieties of andesite, basalt, or diabase constitute the other outcrops. The generalization of Dueñas applied to the entire Department of Cuzco is thus confirmed: "El tipo más general es el de andesitas con hornblenda ó bien con aujita ó todavía con mica negra, presentándose á menudo el caso de tenerse andesitas que además de un piroxeno ó anfíbol, encierran también biotita."³⁰

The lavas at all localities present substantially the same appearance and are believed to represent simultaneous outflows. The rock is but slightly weathered, and the flows retain to a large degree their original topographic expression. They antedate the last period of glaciation, however; the edges of the igneous mass at Ichchu-Orcco have been scored by ice, and till is banked about the base of the Huaccoto volcano. On the basis of these observations the most recent expression of volcanism is tentatively assigned to late Tertiary time. The age of the intrusive rocks is likewise unknown. The igneous mass underlying the fortress of Sacsahuaman penetrates Upper (?) Cretaceous sediments; most of the other dikes and bosses are surrounded by strata of earlier age. It is possible that some of the intrusive rocks are contemporaneous with the beds in which they are now found, a view supported by the presence of ash and tuff in the Pachatucsa and Huayllabamba formations. Detailed field work is necessary before the age relations of the intrusive igneous rocks can be discussed with confidence.

All the igneous masses are in a belt with northwest trend on the north side of the Cuzco Valley, lying between Huatanay and Urubamba rivers, no igneous rocks being found south of the valley axis. When the zone containing the volcanic rocks is extended southeastward it embraces the isolated volcano of Tinta, the hot springs of Agua Caliente, and the great faults bounding the sunken block at Lake Titicaca. Innumerable small faults are also included. It may be that these features indicate a zone of crustal weakness associated with the Tertiary uplift of the Andes.

DESCRIPTION OF AREAS.

The outcrops of igneous rock shown on the geologic map were examined in the field and a suite of specimens was collected. In the microscopic study of the rocks valuable

³⁰ Op. cit., p. 31.

assistance has been given by James S. Stewart, graduate student in the geological department of Yale University, working under the supervision of Professor L. V. Pirsson.

Ttica-Ttica Pass.

Overlooking the ancient highway leading through the pass between Cuzco and Anta is an elongated knob of igneous rock, part of the encircling wall of the Cuzco Basin. The ledge is largely concealed by a superficial cover of weathered material, 4 to 10 feet deep, in which are included large boulders and fragments of blue limestone so thoroughly recemented in places as to present the appearance of a stratum of conglomerate. The igneous rock composing the mass is greenish gray in tone; its texture is microcrystalline except for the presence of minerals of secondary origin, which are abundant, especially in weathered specimens. Epidote occurs in irregular lumps as much as a quarter of an inch in diameter; and the joints in the rock are lined with films of epidote and with sheets, specks, and stellate masses of glistening black hematite, which give to the rock a unique appearance.

When viewed in thin section the rock from Ttica-Ttica Pass is seen to consist of orthoclase, plagioclase, apatite, titanite, and iron ore associated with minerals of secondary origin—epidote, muscovite, chlorite, calcite, and hematite. The plagioclase, which greatly exceeds the orthoclase in amount, is in large part albite with less abundant oligoclase; it occurs as small tabular phenocrysts and as irregular prisms in the groundmass. The crystals of apatite are unusually large for rocks of this class. The few grains of titanite and the very abundant chlorite present no uncommon features. As the rock consists essentially of alkali feldspars it may be termed a syenite.

A quarry on the south slope of the igneous knob has furnished stone for constructing the aqueduct which supplies water to Cuzco and appears well adapted for this purpose.

Sacsahuaman and El Rodadero.

The famous Inca fortress of Sacsahuaman, built of enormous limestone blocks, overlooks the city of Cuzco from a height of 600 feet above the Plaza. The base on which it rests is part of a cliff of igneous rock which for a distance of nearly a mile borders the city on the north. The pavements of steeply inclined streets and ancient terraced gardens conceal the face

of the cliff within the city; along Rio Huatanay (Zappi) its full height is in view and the precipitous ravine of Tullumayu trenches the rock slope from top to bottom. The rock composing the igneous mass is best exposed for study at the top of the cliff, where four knobs or bosses of igneous rock, including El Rodadero, rise above the general surface. All parts of the igneous mass are essentially alike in composition, but the rock presents very different aspects as the result of weathering and the development of secondary minerals. At El Rodadero it appears fresh and firm and the ledge retains the slickensides of an ancient fault plane; in the banks of the Tullumayo groups of concentrically weathered boulders embedded in a disintegrated matrix represent the rock; in the banks of the Huatanay complete decomposition has taken place and only a yellow-white paste containing weathered crystals of feldspar and augite remains. Large masses have been converted into epidote. Hand specimens of the less-altered rock are dark gray in color, with a greenish tinge when viewed in certain lights; weathered fragments are light green or even yellowish and marked with bright-green spots. On the whole the rock is massive, dense, fine grained, and of granitic texture; but even in the freshest hand specimens dark-colored crystals of augite and minute clusters of epidote may be distinguished, thus producing a porphyritic appearance. In certain localities aggregates of yellow-green epidote varying in size from bodies as large as a pea to clusters 8 or 10 inches in diameter are irregularly distributed through the mass and are particularly prominent along joint planes. At a few points the rock contains inclusions 1 to 6 inches in diameter of white and pink marble and of red, brown, gray, and pink quartzite.

When examined under the microscope the rock from Sacahuaman and El Rodadero is found to consist of plagioclase, orthoclase, augite, titanite, apatite, ilmenite, leucoxene, epidote, calcite, chlorite, zoisite, and antigorite. The plagioclase occurs in broad tabular forms of two generations and exhibits albite twinning. Though kaolinized and corroded, probably by hydrothermal action, the plagioclase is subject to analysis by optical methods and found to range in six different sections from albite to andesine with an average composition of about Ab_2An_1 ,—that is, to be slightly more basic than oligoclase. The orthoclase is small in amount, has irregular outlines, and in most sections is replaced by secondary minerals. The augite is green to colorless and occurs in tabular forms and stout

prisms; only in the freshest rock are its original characters preserved; in many specimens it is represented by chlorite, rarely by uraltic hornblende. Hornblende with green color, characteristic cleavage, and crystal outline was observed in only one section. Apatite is sparingly distributed as small prisms and as inclusions in titanite. Black, opaque ilmenite with rhombohedral twinning is displayed as small laths and squares. Titanite, which appears to be both primary and secondary in origin, occurs in irregularly shaped fragments with sharp angles and with characteristic optical properties. Of the secondary minerals chlorite developed after augite and probably also representing hornblende and biotite attains typical development. Colorless to dirty-brown leucoxene is found about the borders and along cleavage planes of the ilmenite crystals. The common calcite and rare zoisite and antigorite present their usual features. Epidote is extremely abundant as grains scattered through the rock, as isolated clusters, and as a coating for cleavage planes; one thin section examined contains practically nothing but epidote. The rock is holocrystalline with granitic to porphyritic texture and may be classed as an augite diorite porphyry.

Two inconspicuous knobs about 2 miles north of El Rodadero are composed of diorite porphyry in less-altered condition than similar rock at Sacsahuaman. The texture is coarse, and partly decomposed phenocrysts of augite assume larger sizes than the minerals of the groundmass. Under the microscope oligoclase feldspar with inclusions of apatite is seen to be the most abundant mineral; orthoclase is rare. Hornblende is well-defined six-sided crystals of dark-yellow tone and shreds of pleochroic biotite are present; the augite is much decomposed and relatively rare. Scapolite, iron ore, muscovite developed after orthoclase, and chlorite occur.

Detached outcrops in the bed of the Huatanay west of Sacsahuaman were not studied, but they appear superficially to resemble closely in composition the rock of El Rodadero.

Stone from the Sacsahuaman mass taken from quarries near the city was highly prized by builders of the Inca dynasty. The best-preserved walls of ancient Cuzco, in which the stones are fitted and polished with incredible skill, are formed of this material (fig. 41).

Huaccoto.

The village of Huaccoto lies at the base of a small volcano. Even at a distance this irregularly shaped ragged mound of bare black rock 400 feet in height presents a striking contrast to the softly molded grass-coated hills and swamp lands which surround it. Near at hand the igneous mass is seen to consist of five knobs separated by basin-like depressions within which drainage is poorly developed. No crater is visible; the lava appears to have emerged intermittently from several vents,

FIG. 41.

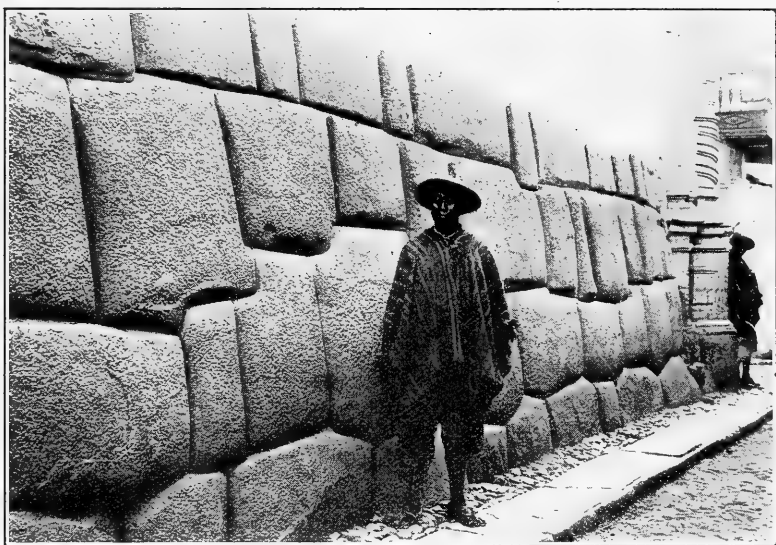


FIG. 41. Inca wall, Cuzco, built of augite diorite porphyry.

making its way to the branched valley of the Huaccoto. The longest continuous flow extends for about half a mile in a southerly direction and terminates in a broken wall 10 to 15 feet in height. The original rough surface of the scoriaceous lava has been greatly modified by the action of frost. Details of vents, ropy structures, and caves are in large part replaced by a superficial cover of broken blocks tilted at various angles.

The unweathered lava is light gray in tone, but weathering produces a uniform color of rich red-brown. The rock varies widely in texture. In some places flow structures are well

developed and amygdaloidal cavities filled with calcite and barite are seen; in other places the rock has a dense groundmass in which phenocrysts of biotite, commonly in well-formed crystals, are prominent. Parts of the flows are massive and microcrystalline. Inclusions of quartzite and of slate and segregations of biotite and of magnetite were noted.

The Huaccoto lava may be classed as hypersthene andesite; its constituent minerals, as revealed by the microscope, are plagioclase, biotite, pyroxene, iron ore, and apatite. The plagioclase, which ranges from andesine to labradorite, occurs as laths and as square prisms with both albite and Carlsbad twinning. The biotite occurs in relatively large brown shreds with characteristic pleochroic colors. The pyroxene crystals, which belong to the orthorhombic variety hypersthene, are displayed as minute prisms ranging in pleochroic colors from greenish yellow to reddish yellow. Iron ore in tiny grains is scattered throughout the section, and prisms of apatite were noted as inclusions in the feldspar. The texture of the rock is hyalopilitic; crystals of feldspar, hypersthene, and biotite are embedded in a groundmass of cryptocrystalline fragments and glass.³¹

The rock from Huaccoto is well adapted for construction. Flow structure aided by jointing favors separation into slabs suitable for paving, curb stones, and door facings; softness and uniformity of texture of selected blocks render it suitable for carved stone work for exterior and interior decoration, and the red color of weathered portions is attractive. These qualities have made the Huaccoto volcano the seat of a quarrying industry for hundreds of years. Rudely paved roads connect the numerous quarries, and the ruins of workmen's huts are surrounded by piles of chips and partly finished blocks. During the Spanish building epoch in particular the Huaccoto lava was extensively used. The façades of the churches at San Geronimo and San Sebastian and of the Jesuit monastery now used by the University of Cuzco were probably built of stone from this locality. Even at the present time a few small quarries are in operation, the stone being carried by llama, burro, or cargador down the difficult trail to villages 3,000 feet below. As compared to the diorite extensively used by the Incas, the basalt from Huaccoto weathers rapidly in the Cuzco climate and where found in ancient buildings it is

³¹ The Huaccoto lava has been previously described by Dueñas (op. cit., pp. 192-193).

chipped, broken, and pitted, and fragments may be pried from columns and lintels with a pen knife. Disfiguration from weathering is however partly compensated by increased attractiveness of color.

Ichchu-Orcco.

The igneous mass of Ichchu-Orcco is topographically a cuesta; its inner face, fronting Cerro Pachatucsa, is a cliff 340 feet high, and its top slopes southward at the rate of about 200 feet to the mile. Neither craters nor lava streams are found, the surface of the rock is worn into knolls and ridges thinly coated with erratics. The absence of features associated with volcanic outflows is not, however, indicative of intrusive origin or of great age, for the entire mass has been glaciated, the evidences of ice work being particularly clear along the west side of the cuesta. The geologic relations of Ichchu-Orcco were not determined. Its history is probably similar to that of Huaccoto, a local volcanic outflow of late Tertiary times.

The igneous material composing Ichchu-Orcco includes two varieties. One is a dense, glistening black rock devoid of cleavage or flow structure, slightly porphyritic with biotite phenocrysts, and very resistant to weathering. In the cliff it presents a rude columnar structure and breaks out into blocks 2 to 4 feet in diameter, controlled by a system of nearly horizontal joints. The other variety is a gray, highly micaceous rock found at and near the surface. This type generally contains minute open cavities even in fresh specimens, and the more weathered portions are commonly amygdaloidal. Boulders found in the stream bed below the igneous cliffs and presumably from this mass, although possibly from the ash of Pachatucsa, exhibit the scoriaceous texture characteristic of surface flows.

Microscopically the two types of rocks are identical in composition, except for difference in weathering and in amount of glass present. The component crystals are plagioclase, biotite, pyroxene, apatite, and iron ore set in a groundmass of minute crystals and glass. The plagioclase occurs as laths, square prisms, and six-sided crystal sections; its composition is intermediate between andesine and labradorite, with about equal quantities of albite and anorthite molecules as determined by the Michel-Lévy method. Brown biotite is present as shreds, crystals, and crossed twins. Pyroxene of two varieties is found—extremely scarce monoclinic diopside of pale-

greenish tone and the orthorhombic variety hypersthene in irregular grains and prisms of green to brown color. The larger crystalline fragments of hypersthene are closely associated with the mica and in some places appear as poikilitic inclusions within spongy biotite crystals. Apatite occurs in prismatic and basal crystal sections; grains of iron ore are widely scattered. The rock may therefore be called hypersthene andesite.

Atascasa.

The geology of the Atascasa area is too complex to admit of a satisfactory interpretation by a reconnaissance survey. Contacts are concealed for the most part by glacial drift, the rocks are faulted and brecciated, and the sediments intruded by igneous masses are themselves in large part composed of igneous material. This area has, therefore, been mapped in a more or less arbitrary fashion, and only the more prominent igneous outcrops are indicated. Ancient intrusive masses which contributed materials for the Pachatuca formation are probably represented, together with dikes of later age. Extrusive rocks contemporaneous with or later in age than the Pachatuca beds are doubtless also present. Exclusive of fragments, many of them tons in weight, incorporated in sandstone and tuff, the igneous rocks examined from this area belong to the trachyte and the andesite families.

The westernmost outcrop shown on the map is a low ridge with cliffs on its southern face and broken by prominent joints trending N. 60° W. The rock is imperfectly gneissoid in structure and pink in tone. Under the microscope it is seen to consist essentially of much-altered pink orthoclase in prismatic and tabular forms. Albite is also present, and apatite occurs with characteristic features. Chlorite, probably derived from the cryptocrystalline matrix, is scattered throughout the section, and glass is present in small amounts. The texture appears to be hyalopilitic. The rock may be classed with trachytes or syenites.

As seen in the ledge the three other areas of igneous rock outlined on the geologic map include massive, bedded, brecciated, and conglomeratic facies. At one point an agglomerate of igneous fragments incorporated with masses of quartzite and sandstone suggests the site of a volcanic pipe. Thin sections cut from specimens collected from the larger igneous masses within the three areas under discussion contain plagio-

clase, the chief mineral, associated with biotite and iron ore. Quartz, calcite, and chlorite occur as secondary minerals. Examination of the least-altered crystals proved the plagioclase to be andesite—in one of the thin sections andesine and labradorite. In one of the specimens studied the iron ore is seen to have resulted from resorption of hornblende in a rock whose original components were probably hornblende phenocrysts set in a plagioclase groundmass. Igneous fragments embedded in the volcanic tuff and breccia have essentially the same composition as the dikes, and the igneous portion of the whole complex may be assigned therefore to the andesite family. The sedimentary rocks associated with the igneous masses at Atascasa are further described on p. 59.

Chchiraura.

Along the east bank of Rio Chchiraura, below the village from which the stream receives its name, igneous rock may be seen penetrating the Huayllabamba sandstones. In the lower portion of the valley the rock is dense and massive; farther up it becomes a tuff. The rock, where fresh, is black to purple in tone, with a dense groundmass in which feldspars are distributed as phenocrysts. Weathered surfaces bring out the porphyritic texture, showing white laths and dark cubes embedded in a gray groundmass.

As revealed by the microscope the dense variety consists of plagioclase feldspar, iron ore, apatite, chlorite, and calcite. The plagioclase, which occurs as phenocrysts and also as minute laths, was determined as labradorite. Apatite in tiny prisms is included in the feldspar. The chlorite and perhaps also the iron ore have probably been derived from a ferromagnesian glassy matrix. The texture is hyalopilitic, but the glass of the groundmass has been greatly modified. The original rock was doubtless a basic andesite; it is so completely altered that closer classification is impossible. Sections prepared from rock near the upper surface of the Chchiraura mass consist essentially of lapilli and ash derived from andesite. The feldspars are albite and oligoclase with lesser amounts of orthoclase and andesine. These crystals of feldspar rest in a groundmass of minute feldspar crystals and abundant grains of iron ore. The iron is secondary in origin, being probably derived from a ferromagnesian glass in the matrix. Calcite, muscovite, chlorite, and a little quartz complete the

list of secondary minerals. This andesitic tuff is believed to be genetically related to the basic andesite over which it lies.

Oropesa.

Between Oropesa and Huacarpay the Rio Huatanay follows the cliff front of an igneous mass nearly 2 miles in length. No crater and no well-defined flows were seen during my brief examination. The surface of the mass, however, is covered with irregular blocks of lava standing at various angles, and along the railroad near Huacarpayropy amygdaloidal lava clearly indicates the extrusive character of at least a part of the mass. As viewed in the hand specimen the fresh rock is dark gray and dense except for innumerable specks of biotite and rounded bits of calcite occupying amygdaloidal cavities. Weathered specimens are light gray with micas of bronze color. The rock has the surface appearance of a scoriaceous minette.

The constituent minerals of the Oropesa lava as revealed by the microscope are biotite, hornblende, augite, plagioclase, iron ore, and calcite. The biotite occurs in long brown, strongly pleochroic plates, as phenocrysts and as smaller shreds in the groundmass. The hornblende is also brown and pleochroic, closely resembling the biotite, from which it differs in crystal outline. Augite occurs in colorless prismatic and elongate sections, rarely twinned. The plagioclase, which presents both laths and tabular forms, was found to be predominately labradorite. Grains of iron ore are few in number and widely scattered. The essential constituents are labradorite, biotite, and augite; hornblende and iron ore are accessory. The texture is hyalopilitic—small laths of feldspar embedded in a matrix of glass. Included in the lava are fragments of gray granite, garnetiferous gneiss, amphibolite, quartzite, and garnetiferous mica schist. In accordance with the classification in general use the Oropesa lava may be termed a basalt or mica basalt.

Sierra-Bella.

At Sierra-Bella, within the canyon of the Urubamba, the remnant of a lava flow forms a terrace rising 150 feet above the river (fig. 42). The terrace front is a wall formed of well-developed columns. On the opposite side of the river, dikes of intrusive rock, essentially like the columnar lava in composition, cut the country rock. It is possible that

these dikes, or similar ones in the immediate neighborhood mark the source of the extrusive masses.

In the hand specimen flow structures and zones consisting chiefly of lithophysæ are conspicuous features of the rock from Sierra-Bella. Under the microscope the extrusive variety is

FIG. 42.



FIG. 42. View looking down the Urubamba River at Sierra-Bella. Lava flow on the right.

seen to consist of labradorite in lath-shaped crystal fragments, biotite in narrow elongated shreds of dark-brown color, and widely scattered grains of iron ore. Calcite and tridymite occur as amygdulæ. In texture the rock is hyalopilitic—a mesh composed essentially of minute laths of feldspar in a groundmass of glass. In a microscopic slide prepared from a

specimen taken from a dike at the south end of the Sierra-Bella bridge the plagioclase was found to be andesine near oligoclase, with the formula Ab_3An_1 . Considered as a whole the igneous rocks at Sierra-Bella may be classed as andesites.

Rumicolca.

The lava field at Rumicolca possesses features of unusual interest. It is the largest exposure of igneous rock within the

FIG. 43.



FIG. 43. Inca wall of hypersthene andesite, Rumicolca quarry. Hiram Bingham, photo.

Cuzco region; its presence is responsible for the position of the lower Huatanay River; stone from Rumicolca was extensively used by Inca and Spanish builders and the present quarries³² are the principal source of rock used in modern construction (fig. 43). Lava flows from at least three centers within this area retain their original forms. Their surfaces are marked by mounds and hollows, and small flows extend like fingers from the sides of the larger masses. Caves and steam cavities are present, and in certain places broken blocks of scoria from the original ropy surface may be seen. Along

³² For a picturesque description of the ancient quarries at Rumicolca see Squier, Peru, pp. 418-419.

the railroad paralleling the Urubamba (here called the Vilcanota) the lavas and associated intrusive rocks form a palisade wall of large columns decorated by radiating sheaves and fans composed of columns of small diameter (fig. 44). It is

FIG. 44.



FIG. 44. Wall of columnar lava lining the canyon of the Urubamba between Cay-Cay and Rajelchi. Leon Campbell, photo.

probable that the lava at this point formerly extended across the Urubamba, thus effecting an important modification in the drainage.

As viewed in the ledge the rock from Rumicoclea is of two types, which, however, grade into each other—(1) a massive rock of light-gray tone, microcrystalline except for the presence of flakes of biotite which dot the surface; (2) a banded rock with alternate belts of white, light gray or pink, and dark gray or black. The bands occur as individuals or in series and vary in width from threads to ribbons 2 to 3 inches wide. Both types of the rock are in places amygdaloidal, and in the banded variety lithophysæ are common. These evidences of former fluidal condition are supplemented by the parallel arrangement of part of the biotite. Fragments of sandstone are incorporated within the lava.

Microscopic examination shows the rock to consist of plagioclase, pyroxene, hornblende, biotite, and iron ore set in a dense glassy groundmass. Transparent tridymite traversed by numerous cracks fills the larger cavities. The laths of plagioclase twinned according to the Carlsbad law were determined as bytownite. Hypersthene is the variety of pyroxene present; it occurs as distinct pale-green pleochroic prisms and also as irregular masses included within the hornblende. All the hornblende present is the brown variety common in basalts and is much corroded. Biotite of characteristic aspect is a prominent constituent. The texture is hyalopilitic to fluoidal and the rock may be classed with the hypersthene basalts.³³

Tinta.

The volcano of Tinta, 75 kilometers southeast of the Rumicoclea, is a conspicuous landmark on the Juliaca-Cuzco Railroad. The topographic forms of the cone and the sprawling outflows of lava are but slightly modified by erosion. Weathering of the black scoriaceous lava is insignificant, and the cavities within the rock are almost free of secondary filling.

The lava of the Tinta volcano is a pyroxene andesite. The constituent minerals are oligoclase, augite, hypersthene, biotite, apatite, and iron ore embedded in a dark microcrystalline and glassy matrix. Both fluoidal and amygdaloidal textures are present. A detailed description of the Tinta lava is given by Dueñas.³⁴

³³ Under the name "labradorita á biotita" Dueñas (op. cit., p. 192) describes a rock "que afloran en la sección comprendida entre Urcos y Sierra Bella" which may have been collected from the Rumicoclea quarry.

³⁴ Op. cit., pp. 190-191.

ART. II.—*An Achromatoscope**; by S. R. WILLIAMS.

THE dark center of Newton's rings is explained as being due to the interference of two rays of light reflected from two optical surfaces so close together that only a half wave length exists in the difference of path between the two rays and this difference is due to change in phase at one of the surfaces of reflection. In other words, the two surfaces are in contact and the change in phase introduced at one surface is half an undulation for all wave lengths as Young showed by means of an oil of sassafras film between crown and flint glass surfaces. For an air film then, the central spot of Newton's rings is black for all wave lengths because we have destructive interference for a difference in path such that,

$$2\mu d = (2N + 1) \frac{\lambda}{2} \quad (1)$$

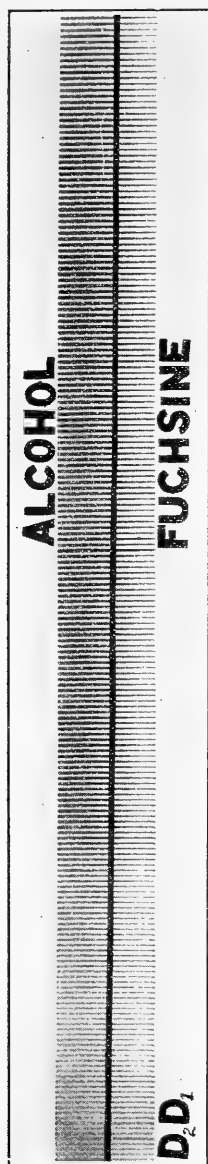
i. e., for an odd number of half wave lengths, where N is the order of interference, d the thickness of the film, μ the index of refraction and λ the wave length. When white light, reflected from this portion of Newton's rings, is examined spectroscopically only a faint spectrum may be seen as a little more light is reflected from the front surface than from the rear of the film.

(a) *Effect of Separating the Two Optical Surfaces.*

If now the two optical surfaces are slowly separated an interesting phenomenon occurs in the field of view of the spectroscope; light begins to push in from the violet end of the spectrum in the form of a broad bright band which moves toward the red end of the spectrum. For any particular wave length in the spectrum past which the center of this broad band of light passes, it means that the difference in path has been increased by a half wave length or that the total difference in path is now a whole wave length for that particular point in the spectrum, where the center of the band lies. This also means that the two surfaces have been separated by a distance equal to a quarter of the wave length just mentioned. As the surfaces are still farther separated the broad band keeps pushing out toward the end of the spectrum where the wave length is infinite, λ_{∞} . Other light bands but somewhat narrower are following this first one. For the second light band

* Read by title at the New York meeting of Amer. Phys. Soc., Oct. 31, 1914. Abstract, Phys. Rev., vol. iv, p. 550, 1914.

FIG. 1.



the difference in path between the two interfering rays is $4/2$ times the wave length past which the center of the band is moving. Thus for successive light bands, which move through the spectrum, we need only to multiply a half wave length by an even number to get the difference in path for that particular wave length at which the center of the band comes. For the light bands in general, we have the relation holding:

$$2\mu d = 2N\lambda/2, \quad (2)$$

where the various letters have the same significance as in equation (1).

When the surfaces are sufficiently separated a continuous spectrum will be lacking certain wave lengths for which the difference in path of the two interfering rays is an odd number of half wave lengths. The resulting spectrum is known as a channeled spectrum (see figs. 1 and 2) and may be applied to various optical measurements.

To confine our attention more definitely to some particular point in the spectrum, say λ_D , it will be noted that by counting the number of light bands which pass λ_D we have at once the particular order of interference for λ_D , if we started to count with the first light band which pushed in from the violet end. If N_D is this order of interference for λ_D and we could see all of the bands lying between λ_D and λ_∞ , the number would also be N_D . This may be expressed by the formula,

$$N_D - N_\infty = N_D \quad (3)$$

which says that the total number of bright bands passing λ_D is equal to the number of bands in the spectrum between the wave lengths, λ_D and λ_∞ . Let the two optical surfaces be still farther separated so that more bands

push along toward the red end, then N'_D , the order of interference for the band now resting at λ_D , will be equal to the

total number having passed λ_D , or the total number lying between the limits, λ_D and λ_∞ . This may be expressed by the equation,

$$N'_D - N_\infty = N'_D. \quad (4)$$

In changing the order N_D to N'_D a certain number of bands have passed λ_D . Let this number be m , whence,

$$N'_D - N_D = m. \quad (5)$$

At some other point in the spectrum, say λ_F , a similar variation has been going on, viz.,

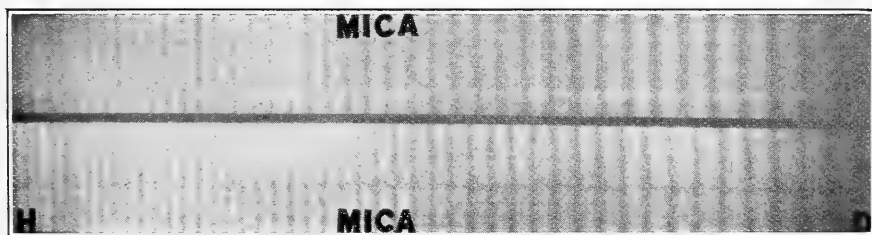
$$N_F - N_\infty = N_F. \quad (6)$$

Thus while N_D was changing to N'_D so N_F was changing to N'_F , hence,

$$N'_F - N_F = n \quad (7)$$

where n is the number of bands passing λ_F while m bands were passing λ_D , and since $\lambda_D > \lambda_F$, $n > m$. Moreover, since

FIG. 2.



a band either to the right or left of any given band means either an increase or a decrease in order of one, it follows that the number between λ_F and λ_D is given by the relation

$$N_F - N_D = p_1 \quad (8)$$

$$N'_F - N'_D = p_2 \quad (9)$$

where p_1 is the number of bands between λ_D and λ_F before the difference in path of the two rays was varied and p_2 is the number after the change. If equation (5) is subtracted from equation (7) and the difference compared with what follows from subtracting equation (8) from equation (9), it will be seen that

$$n - m = p_2 - p_1, \quad (10)$$

that is, the increase in the number of bands between λ_D and λ_F is equal to the greater number of bands which pass λ_F than λ_D

in changing the thickness of the film. To put it in other words, if a yard contains a certain number of sheep and a greater number are driven in on one side than are let out on the other the number in the yard will be increased. When the difference in path is made any multiple of what it was before the change, then that same number will also indicate the ratio of the number of bands lying between any two wave lengths before and after the change was made. For instance, let $N'_D/N_D = 2, 3, 4$ or 5 , etc., then p_2/p_1 will also equal $2, 3, 4$ or 5 , etc. Let us make $p_2/p_1 = r$ and then

$$\frac{N'_D}{N_D} = \frac{N'_F}{N_F} = \frac{p_2}{p_1} = r. \quad (11)$$

We are now in a position to obtain a numerical value for N_D even if we have not commenced to count when $N_D = 0$, for from (5) and (11) we obtain

$$N_D = \frac{m}{r-1}. \quad (12)$$

Equation (12) is the one obtained by the late Professor D. B. Brace* in a paper on the use of spectral bands. This rather visualized method for deducing it is given here in the hope that attention may be drawn to the importance of the equation in certain optical measurements. The form of the equation as first derived by Brace† and used by his pupils was

$$N_D = \frac{mr}{1-r}.$$

The only difference in the two formulæ is that the r in one is the reciprocal of the r in the other. Either form is correct if properly interpreted.

Suppose we have a thin transparent film of any substance, refracting or otherwise, and if light, reflected from the front and rear surfaces of the same, is allowed to illuminate the slit of a spectrometer, a channeled spectrum will appear in the field of view. If we count the number of bands, p_1 , between any two definite points in the spectrum and by any means whatsoever we can vary continuously the thickness of the film so that m bands pass a selected wave length and again count the number of bands, p_2 , between the two definite points between which p_1 was counted, then the order of interference may be determined for the wave length past which m bands defiled in changing the thickness of the film. This is an interpretation of equation (12).

* Brace, *Phys. Rev.*, vol. xxi, p. 289, Nov., 1905.

† Brace, *Phil. Mag.*, p. 350, Oct., 1899; *Phys. Rev.*, vol. xviii, p. 280, Apr., 1904.

Heretofore we have always had to know the index of refraction of the substance and the thickness of the film in order to find the order of interference, but equation (12) is independent of both of these as was not the case for equations (1) and (2), hence, as the author* has shown in previous work, we have at our disposal a powerful method for determining the indices of refraction or studying dispersion.†

(b) *Projection of Newton's Rings on the Slit of a Spectrometer.*

If on the other hand, we should project by reflection the image of a set of Newton's rings on the slit of a spectrometer in such a way that the rings were bisected by the slit, then the phenomenon observed in the resulting spectrum is a bird's-eye view at once of all of the successive changes which occurred when the two surfaces were mechanically separated. For that portion of the slit covered by the center of the rings there will be a dark horizontal band running throughout the spectrum, while above and below this band there will appear other dark bands which are inclined to the dark central band. These dark bands are simply those places in the spectrum where for certain wave lengths there is an odd number of half wave lengths difference in path between the two interfering rays. The result is, that if the space between the optical surfaces be considered wedge-shaped along a direction parallel to the slit and the spectrum is a normal one, then in that spectrum there will be straight interference bands which are more nearly parallel to the central horizontal band, the nearer the approach to the center of the rings is made; while for greater distances away from the center the bands become more nearly parallel to the slit. An attempt has been made to show this graphically in fig. 3, where at the left of the figure is shown the wedge-shaped film of air ($\mu = i$ approximately) from which white light is reflected on to the slit, while the corresponding position of the bands in the spectrum are shown to the right. In fig. 4 a photograph of a limited portion of the spectrum is shown with these bands appearing. Figs. 3 and 4 were made with the center of the rings at the lower end of the slit, hence these two cuts may both be thought of as quadrants of what actually exists in a grating spectrum, when the dark center is at the center of the slit.

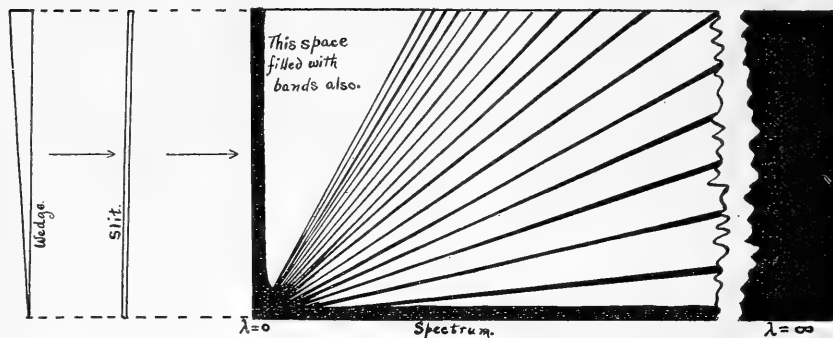
If the wedge-shaped film is formed from a dispersive medium then the bands become in a measure dispersion curves,

*Phys. Rev., vol. xviii, p. 280, 1904; xxvii, p. 27, 1908.

†Feussner, as late as 1906, stated that the determination of indices of refraction by means of interference phenomena depended upon equation (2). Winkelmann, Handbuch der Physik, vol. vi, p. 979.

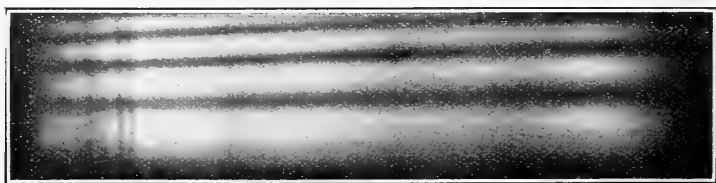
and we can interpret at once the type of dispersion the medium will show. For the sake of brevity these interference bands may be called interference dispersion curves. The conditions for anomalous dispersion are very interesting. If at any point in the spectrum $d\mu/d\lambda = 0$ or < 0 , we say that the substance shows anomalous dispersion. This does not mean however

FIG. 3.



that points of inflection will be shown in the interference dispersion curves from the films of substances possessing anomalous dispersion. In an anomalous region, if the index of refraction decreases it will tend to broaden the bands while for an increase of refraction it will tend to make the bands closer

FIG. 4.



together. Thus at G in fig. 5 the index has suddenly decreased and we see the bands curve more sharply outward, while at F where the index increases the bands have curved inward toward the central band.

Even in a non-dispersive substance the interference dispersion curves are uniformly receding from the central band and this recession must be overcome in order to show points of inflection in the curves we are dealing with. This much can

be said however, that for interference dispersion curves in which points of inflection do occur there can be little doubt but what that substance shows anomalous dispersion. In fig. 5 is shown a rough drawing of interference dispersion curves from a thin film of a concentrated solution of alcohol and fuchsine in which points of inflection do occur. Some excellent photographs showing these inflections in interference dispersion curves may also be seen in an article by W. H. Julius,* who used a Jamin interferometer for getting the interference

FIG. 5.



FIG. 5. Interference dispersion curves from a thin film of concentrated alcohol-fuchsine solution. Satisfactory cuts could not be made from original photographs.

effects. Fricke† and Puccianti‡ have also studied the dispersion of absorbing media by methods which suggest that given in this paper. This method also recalls the method of crossed prisms used by Newton§ and the crossed prism and grating method of Wood.||

As stated in the beginning of (b) when the image of the rings of Newton is projected on the slit of the spectrometer a view is had at once of all the steps which occur when the optical surfaces are slowly separated as in (a). In projecting the rings of Newton on the slit of the spectrometer care must be taken that they are centrally placed, otherwise distorted interference bands will occur. A wedge-shaped film, of course, obviates this difficulty.

Another way of showing this relation is to use a long narrow slit, the length of the spectrum, and move the same parallel to itself and to the central band. Whatever appears in the narrow slit will be some step which has occurred when the surfaces were separated in (a). If along any Fraunhofer line one counts the number of interference bands between this slit and the central band, the number of bands will give the order of interference for the thickness of film which is located at a dis-

* Julius, *Astrophys. Jour.*, July, 1914.

† Fricke, *Drude's Annal.*, xvi, p. 865-889, 1905.

‡ Puccianti, *Nuovo Cim.*, ii, p. 257-264, 1901.

§ Newton, *Opticks*, book 1, Prop. 2, theorem 2.

|| Wood, *Physical Optics*, p. 115, ed. 2.

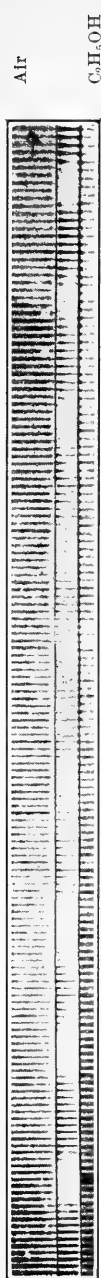


FIG. 6.

tance from the center of the rings equal to the distance this long slit is from the central band. Equation (12) is applicable here also.

There remains one other simple device for studying the dispersion of a medium where the interference bands from a thin film of the substance is at hand as in fig. 1. In equation (2) we see by differentiating N with respect to λ that for non-dispersive substances, and air may for all practical purposes be taken as such, that

$$dN/-d\lambda = 2D/\lambda^2, \quad (2a)$$

while for a dispersive substance,

$$dN/-d\lambda = \frac{2D}{\lambda^2} \left(\mu + \frac{\lambda d\mu}{-d\lambda} \right). \quad (2b)$$

The quantity in parenthesis is the factor which will, in general, cause the interference bands from the dispersive film to crowd together more rapidly than those from an air or vacuum film as one goes toward shorter wave lengths in the spectrum. Hence, superimposing a set of air bands upon a set of bands from a dispersive film, there will be found interference effects between the two sets of bands as they get out of step with each other. This is shown in fig. 6 where a set of air bands has been superimposed upon a set of bands from a thin film of alcohol. The photographic plates were made to overlap part way and then printing on "Velox" paper occurred through the overlapped plates. This gives simultaneously the air bands, the alcohol bands and the bands due to superposition. If the air bands are shifted so that the distances between the bands become more nearly like those between the bands from the dispersive film, then the interference bands due to superposition become less and less and any irregularities in dispersion are very easily picked out. A set of air bands may be photographed once for all and then used as comparison bands for any other set of bands taken from a dispersive film.

(c) *Tests for substances to be used in Achromatic lenses.*

This paper wishes to point out particularly the effectiveness of spectral bands in studying transparent substances in order to find achromatic combinations. The method employed here has especial significance when applied to thin films of various kinds of glass in order to select combinations which will produce the best achromatic lenses. Preliminary work in testing the achromacy of various liquids would indicate that for some purposes liquid lenses might be used to a great advantage. The liquids would have to be held in glass containers which were ground to the proper curvature, but whose walls were parallel surfaces.

The arrangements adapted to testing substances for achromatic combinations have been called achromatoscopes because without the necessity of measuring the refractive indices we can tell by inspection whether there is achromacy or not. The various systems consist essentially of devices for viewing two spectra in juxtaposition in which one is a channeled spectrum from one film and the other is from another thin film. Any comparison spectrometer may be used.

If the interference bands in both spectra are in coincidence throughout the spectra then perfect achromatization exists, for the condition of achromacy is fulfilled, viz., that

$$\frac{dN_1}{-d\lambda} = \frac{dN_2}{-d\lambda}. \quad (13)$$

This condition is shown in fig. 1 for that section of the spectrum between the C and D lines where the channeled spectrum from a thin film of absolute alcohol is compared with a solution of fuchsine and absolute alcohol (concentration 1:0.000072 by weight). Perfect achromatization may be present even though the interference bands are not in coincidence. The necessary and sufficient condition is expressed in (13). When coincidence or approximate coincidence occurs it will be found much easier to determine whether achromatization is present or not. In fig. 2 is shown a comparison of channeled spectra from two mica films. The bands are not in coincidence but (13) does hold. It will be evident from a comparison of figs. 1 and 2 that any departure from achromatism can be detected most readily when the nearest approach to coincidence of bands is sought for.

The best mechanical arrangement for comparing channeled spectra is that shown in fig. 7. A slit, S_1 , is illuminated with sunlight so that in the resulting spectra, wave lengths may be determined from the Fraunhofer lines. By means of a lens, L_1 , and two right angled prisms, p_1 and p_2 , placed on top of

each other, the image of the illuminated slit is thrown on the two wedge-shaped films, f_1 and f_2 . The two wedge-shaped films may be moved parallel to their lengths by means of screws which extend forward to the observer seated at the

FIG. 7.

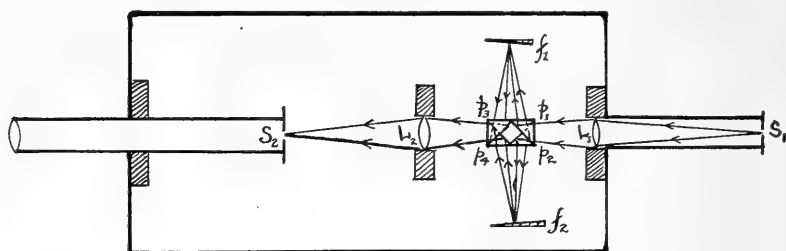
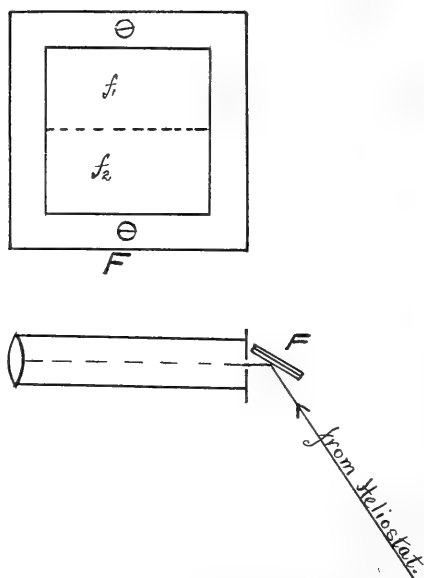


FIG. 8.



eye-piece of the telescope. This affords a means of changing the order of interference in either one of the films and of bringing the spectral bands into coincidence as nearly as possible. The two sets of light rays from the two surfaces of the films are now returned to the right angled prisms, p_1 and p_2 . These two prisms are arranged as p_1 and p_2 , and throw the light through the lens, L_2 , so that the image of the image of the

slit, S_1 , is formed at S_2 where the slit of the spectrometer ordinarily comes. The upper half of the slit image is light from one film and the lower half from the other wedge-shaped film. The lenses, L_1 and L_2 and the prisms, p_1 , p_2 , p_3 , and p_4 should be good ones.

In fig. 8 is shown a very simple device for mounting two films in comparison work. The films are fastened edge to edge in a frame, F , which is placed before the slit of the spectrometer at an angle of about 45 degrees with the axis of the collimator tube. The sunlight reflected from the upper film may be made to illuminate the upper half of the slit while that from the lower film will illuminate the lower half of the slit. The channeled spectra in fig. 2 were taken in this way, which of course does not permit shifting of one film with respect to the other although such an arrangement could be easily made.

Optical concerns investigating the various kinds of glass which they use in achromatic combinations ought to find an achromatoscope, such as described in the foregoing pages, a convenient method for rapidly testing the various specimens of glass submitted. The figuring of thin wedges ought to be no more laborious than an ordinary prism and once secured does not require such elaborate measurements as the prism method.

Summary.

1. The theory for determining the optical thickness of a film without knowing either its actual thickness or its index of refraction has been developed in a simple manner.

2. A method for the study of the dispersion of a substance has been developed, using a wedge-shaped film when the refracting edge is normal to the slit of the spectrometer. This method is applicable to anomalous dispersive substances.

3. Application of channeled spectra to a study of achromatic combinations has been pointed out and a practical device developed for rapidly testing various kinds of glass for achromatic combinations.

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ART. III.—*The Life of Radium*; by ELLEN GLEDITSCH.

[Contributions from the Sloane Laboratory of Yale University.]

SOME years ago Professor B. B. Boltwood indicated a very direct method for determining the disintegration constant of radium, and also made some determinations of it.* It was at that time generally recognized that radium was a disintegration product of uranium; it was known that the two elements uranium and radium occurred in nearly constant proportion in the uranium minerals. On the other hand several attempts to prove the growth of radium in uranium solutions had failed, so it was probable that the production of radium from uranium-X was not a direct one, but took place through an intermediate long-lived substance. Boltwood † succeeded in 1907 in finding a new substance in the radioactive minerals; this new element, ionium, produced radium at a measurable rate. It therefore seemed possible to determine the constant of change of radium from the growth of radium in ionium preparations. Boltwood's experiments consisted in a separation of the ionium from known quantities of uranium minerals and the comparison of the amounts of radium produced by the separated ionium in known periods with the amounts of radium associated with it in the minerals.

The radium present in a mineral was determined by measuring the activity of the equilibrium amount of radium emanation evolved from an average sample of the mineral and by comparing it to the activity of the emanation from a solution containing a known amount of radium. The solution containing the ionium from a mineral was sealed up in a glass bulb, and from time to time the radium emanation which had accumulated in it was boiled off and its activity measured. The quantity of emanation present is a measure of the radium present in the solution, though for short periods of accumulation the quantities are not directly proportional.

The mathematical discussion of the problem has been published by Rutherford.‡ The amount of radium present in an ionium solution at any time consists of two separate factors: the quantity present with the ionium at the start and the quantity formed by the ionium in the time passed since the start. If a quantity of radium, q_0 , is present in the ionium solution at the start, the emanation will accumulate and after a time t will be equal to

$$q_0(1 - e^{-\lambda t})$$

where λ is the disintegration constant of the emanation.

* This Journal, xxv, 493, June 1908.

† This Journal, xxii, 537, 1906 and xxiv, 370, 1907.

‡ Phil. Mag., xiv, 733, 1907.

The radium formed in the solution can be expressed in terms of its equilibrium amount of emanation q . If a solution of ionium is sealed up, and radium produced at a constant rate, then the amount of emanation after a time t (in days) will be proportional to

$$q_t - \frac{q}{\lambda}(1 - e^{-\lambda t})$$

And the ratio of the amount of emanation present to the amount in equilibrium with the radium present will be

$$\frac{q_t - \frac{q}{\lambda}(1 - e^{-\lambda t})}{q_t} = 1 - \frac{1}{\lambda t}(1 - e^{-\lambda t}).$$

The total amount of emanation after a time t will be equal to:

$$q_0(1 - e^{-\lambda t}) + q_t \left[1 - \frac{1}{\lambda t}(1 - e^{-\lambda t}) \right]$$

t being always the time in days.

Boltwood's results showed that the growth of radium in the solution was constant for the periods of time over which it was observed. This indicated that the ionium itself changed very slowly, and that it was the immediate parent of radium. The result may be said to justify the use of ionium for the determination of the period of change of radium. The method has further the great advantage that the results are absolutely independent of any radium standard. The results of the separate measurements are given in terms of radium for the sake of convenience; they might equally well be expressed in arbitrary units.

It is evident that the justification of using this method lies in the possibility of separating completely the ionium from the minerals. Boltwood in part used ionium solutions prepared from very impure materials. But one of his solutions was prepared from a very pure uraninite and was prepared with special care. The growth of radium in this solution gave a value for the constant of change of radium equal to: 3.48×10^{-4} , which corresponds to a half-value period of 1990 years.

This result has been generally accepted and agrees approximately with the values found by more indirect methods.

Another calculation of the period has been made by Rutherford and Geiger from the number of α particles emitted per second per gram of pure radium. The period found was 1760 years. It is obvious that the accuracy of this determination depends upon the purity of the radium salt used. Rutherford*

* Phil. Mag., xxviii, 320, Sept. 1914.

has corrected the number according to the International Standard and gives the value as 1690 years.

The disagreement between this value and the 2000 years found by Boltwood is too large and makes it important to redetermine the constant of radium.

Mr. Boltwood suggested that I undertake this determination and I have done it partly in the Sloane Laboratory at Yale University, New Haven, Conn., partly at the University in Kristiania, Norway.

During the time elapsed since Mr. Boltwood made his determinations of the period, nothing has been found that might in any way make the method less reliable. The determination of radium in solutions by measuring the activity of the emanation has proved an absolutely sure and satisfactory method. Later research concerning ionium seems to indicate that this substance has a still longer life than was previously supposed, which makes it still more fitted for our experiment. And finally, later experiments concerning the ratio between uranium and radium in minerals have shown that exceptions from the constant ratio are to be found in minerals of later origin, but at the same time the ratio proves to be extremely constant in primary uraninites.

Mr. Boltwood kindly permitted me to measure one of his old solutions that had served for his determination in 1908. It was the solution which he trusted most, given as Ionium Solution 5 in his paper.* I made two measurements and calculated the values from these and Mr. Boltwood's first measurement made about 6 years earlier.

No.	Days from start	Growth of radium per day
1	2423	0.00968×10^{-9}
2	2450	0.00978×10^{-9}

I give these values in terms of the international standard. According to the standard used by Mr. Boltwood, they would give:

$$\begin{aligned} &0.01016 \times 10^{-9} \\ &0.01027 \times 10^{-9} \end{aligned}$$

Mr. Boltwood in his paper gives 0.0102×10^{-9} gram.

The agreement is surprisingly good and proves in a definite way that the production of radium in ionium solutions is constant and further that the rate of change of ionium is very slow. It thus offers the best evidence of the reliability of the method.

Thus no fundamental objection can be raised against Boltwood's method.

* Loc. cit.

The chief point will then be to make sure that all ionium has been removed from the mineral. The following method was adopted. All the rare earths contained in a mineral solution were precipitated and removed by filtration. To the solution was added a solution of a small quantity of rare earths containing no radium or ionium and the precipitation was repeated. After filtration a new quantity of rare earths was brought in the solution and precipitated. The first two precipitates were put together and, after a treatment, that will be described later, were brought into solution and formed the *main solution*. The third precipitate was treated separately but in exactly the same way and constituted the *test solution*.

If this test solution showed no growth of radium there could be no doubt that all ionium had been removed from the mineral and was in the main solution.

Experimental Results.

I shall now give a short description of the preparation of the ionium solutions and the measurement of the growth of radium in them.

1. Ionium solution from Uraninite, North Carolina.

The mineral was a very pure uraninite carefully freed from all alteration products; it contained 69·4 per cent uranium. 110 grams of the finely powdered mineral were dissolved in warm nitric acid (30 per cent). The solution was evaporated to dryness, the residue was moistened with nitric acid and dissolved in hot water. Filtration left only a very slight residue. This residue was treated with hydrofluoric acid and evaporated with some drops of sulphuric acid. A dilute hydrochloric acid dissolved most of it; the undissolved part was melted with potassium hydrosulphate and then it was completely dissolved in water which was acidified with a little hydrochloric acid. These two solutions were both precipitated with ammonia and the slight precipitates were dissolved in dilute nitric acid and added to the mineral solution.

The main solution was now treated with an excess of hydrogen sulphide, the sulphides formed were removed by filtration and a current of air was passed through the solution in order to expel the hydrogen sulphide. The solution was heated to boiling and some grams of oxalic acid were added. The solution was left over night and the oxalates formed were filtered off (1). A solution containing about 1·25 grams of rare earths, mostly thorium, was added to the filtrates and, after heating, the earths were precipitated by oxalic acid (2). After removal of the oxalates 1·25 grams of rare earths were again added to the filtrate and then an excess of oxalic acid; the oxalates (3)

were filtered off. All the oxalates precipitated 1, 2 and 3 were gently heated together and the oxides formed converted into sulphates and brought into solution. The hydroxides were precipitated several times in order to remove all radium and the final precipitate was dissolved in dilute hydrochloric acid and introduced into a glass bulb where the growth of radium could be measured from time to time. The results are given in Table 1: Solution 1 from uraninite, North Carolina.

TABLE 1.

Growth of radium in the main solution from uraninite, N. Carolina.

Test	Time from start in days	Radium emanation found expressed in terms of radium	Growth of radium per day
1	8.75	0.228×10^{-9}	
2	46.00	1.07×10^{-9}	0.023×10^{-9}
3	77.00	1.86×10^{-9}	0.024×10^{-9}
4	100.00	2.31×10^{-9}	0.023×10^{-9}
5	541.00	13.11×10^{-9}	0.024×10^{-9}

Average growth of radium per day, 0.024×10^{-9} gram.

The mineral solution was evaporated to dryness and the oxalic acid destroyed; the residue was moistened with nitric acid, evaporated to dryness and dissolved in warm water. Nearly three grams of rare earths were added and again precipitated with oxalic acid. The oxalates were filtered off, treated exactly as the first ones and brought in solution in a glass bulb, where the growth of radium was measured. The growth of radium is shown in Table 2.

TABLE 2.

Growth of radium in test solution from uraninite, N. Carolina.

Test	Time from start in days	Radium emanation found expressed in terms of radium	Growth of radium per day
1	7.06	1.345×10^{-9}	
2	98.00	1.970×10^{-9}	0.001×10^{-9}
3	511.00	4.62×10^{-9}	0.00092×10^{-9}
4	540.00	4.90×10^{-9}	0.0009×10^{-9}

Average growth of radium per day, 0.001×10^{-9} gram.

I had expected this solution to be free from ionium, but this was not the case. I therefore repeated the operations once more, added rare earths, precipitated them with oxalic acid, transformed the oxalates and finally got a third solution: Solution 3 from uraninite, N. Carolina.

TABLE 3.

Growth of radium in test solution from uraninite, N. Carolina.

Test	Time from start in days	Radium emanation found expressed in terms of radium	Growth of radium per day
1	2.72	0.312×10^{-9}	0.00005×10^{-9}
2	486.00	0.838×10^{-9}	

The solution shows no appreciable augmentation of radium and may be considered free from ionium. There is every reason to believe that all the ionium was contained in the first two solutions.

The entire growth of radium was :

$$\begin{aligned} &\text{per day : } 0.025 \times 10^{-9} \\ &\text{or per year : } 9.13 \times 10^{-9} \end{aligned}$$

The radium present in the solution at the start was :

$$0.13 \times 10^{-9} \text{ .gram.}$$

The amount of radium in the mineral was determined in an average sample. 110 grams of mineral contained 2.46×10^{-5} grams of radium.

$$\text{Ra} = \frac{9.13 \times 10^{-9}}{2.46 \times 10^{-5}} = 3.71, 10^{-4} (\text{year})^{-1}$$

The half-value period of radium is given by :

$$\begin{aligned} \lambda T &= \log_e 2 \\ \text{or : } T &= \frac{\log_e 2}{\lambda} = \frac{0.693}{3.71, 10^{-4}} = 1865 \text{ years.} \end{aligned}$$

The growth of ionium in this first ionium solution already indicates that the period found by Boltwood (2000 years) is too high. At the same time it must be admitted that the precipitation as oxalates has not been a very effective one; and 4 per cent of the ionium is found in the test solution.

2. *Ionium solution from Cleveite, Norway.*

Cleveite is a primary uraninite containing about 10 per cent of rare earths; it occurs in pegmatite dikes in Norway. The sample used was from Saetersdalen. 180 grams of the mineral were treated with nitric acid (30 per cent) and most of it dissolved quickly. The residue consisted chiefly of silica and a further treatment with hydrofluoric acid and sulphuric acid reduced it to about five grams. This residue showed an activity about three times that of uranium and probably contained a little radium. It was ignited with sodium carbonate, and the fused mass was heated with water and a little hydrochloric

acid. The filtered solution contained no uranium. The residue weighed only 2.13 grams and its activity was negligible.

The cleveite solution was treated with hydrogen sulphide and the sulphides were removed by filtration; the hydrogen sulphide was expelled from the solution by a current of air. The solution was heated to boiling and oxalic acid was added; the precipitate formed was not so large as I expected and I believed that the precipitation was not at all complete. I now made several other solutions of small quantities of cleveite using different solvents and I tried various methods of precipitating; but I always found that the precipitation of the rare earths as oxalates was an unsatisfactory one. The precipitation as fluorides* seemed much better to me. I therefore removed the oxalates formed in the main solution, evaporated the liquid to dryness,† destroyed the oxalic acid and dissolved the residue in water and hydrochloric acid. The solution was boiled and an excess of hydrofluoric acid was added.

The liquid was allowed to cool and the precipitate, which was at first very voluminous, settled down as a heavy powder, that could easily be filtered off. It is obvious that to work with large quantities of hydrofluoric acid is very slow; the platinum dishes available in an ordinary laboratory are not large and it was necessary to precipitate only small portions of the mineral solution at a time. But the precipitation is so much better and more complete, that there can be no doubt that this method ought to be preferred for minerals like cleveite. The fluorides were filtered off and a solution containing two grams of oxides of rare earths‡ were added. The earths were again precipitated as fluorides and removed. The fluorides were heated and by addition of sulphuric acid and ignition converted into sulphates. All the sulphates were dissolved and the hydroxides precipitated several times with ammonia. The final precipitate was dissolved in dilute hydrochloric acid and brought into a glass bulb; the results of the measurements are given in Table 4.

In the mineral solution a new quantity of rare earths was added and precipitated with hydrofluoric acid; the precipitate was treated exactly as the main precipitate, and after solution it was placed in a glass bulb: Test solution from cleveite.

* See Keetman. Thesis, Berlin 1909.

† During this evaporation a slight accident occurred. A loss of ionium will give a period of too high value. The result in the cleveite solution consequently has to be considered as a maximum value.

‡ The oxides of rare earths added here and in other solutions had all been prepared earlier from the Norwegian mineral gadolinite; they consisted chiefly of yttrium earths with some cerium earths. The amount of thorium in the gadolinite was very slight and it contained no uranium.

TABLE 4.

Growth of radium in the main solution from cleveite.

Test	Time from start in days	Radium emanation found expressed in terms of radium	Growth of radium per day
1	1·83	$0·82 \times 10^{-9}$	$0·0342 \times 10^{-9}$
2	34	$3·756 \times 10^{-9}$	$0·03405 \times 10^{-9}$
3	80	$5·310 \times 10^{-9}$	$0·0342 \times 10^{-9}$
4	144	$7·507 \times 10^{-9}$	
5	192	$9·119 \times 10^{-9}$	$0·0340 \times 10^{-9}$

Growth of radium per day : $0·0341 \times 10^{-9}$ gram.

per year : $12·45 \times 10^{-9}$ gram.

TABLE 5.

Growth of radium in test solution from cleveite.

Test	Time from start in days	Radium emanation found expressed in terms of radium	Growth of radium per day
1	3·83	$0·33 \times 10^{-9}$	
2	41·	$0·30 \times 10^{-9}$	
3	104·	$0·33 \times 10^{-9}$	0·00

There is no augmentation of radium in this solution and consequently it contains no ionium. The precipitation by hydrofluoric acid so proves to be very complete.

The growth of radium in the cleveite solution is :

per day : $0·0341 \times 10^{-9}$ gram.

per year : $12·45 \times 10^{-9}$ gram.

The amount of radium present in the solution at the start was $2·8 \times 10^{-9}$ gram.

The radium contained in 180 grams of the mineral was $3·19 \times 10^{-5}$. The fraction λ of the radium changing per year was therefore :

$$\frac{12·45 \times 10^{-9}}{3·19 \times 10^{-5}} = 3·90 \times 10^{-4} \text{ (year)}^{-1}$$

and the half-value period of radium is :

$$T = \frac{0·693}{3·9 \times 10^{-4}} = 1777 \text{ years.}$$

3. Ionium solution from Bröggerite, Norway.

Bröggerite is a well-crystallized uraninite from Raade, Norway. It crystallizes in the regular system and can easily be separated from accompanying minerals except columbite. This mineral, which contains tantalates and niobates of iron,

manganese and rare earths, sometimes covers the crystal faces of the bröggerite and then cannot be separated completely from it. But while the bröggerite dissolves quite easily in nitric acid, the columbite is not attacked and is left in the residue.

200 grams of mineral were treated with nitric acid (30 per cent). All the bröggerite was dissolved and the solution was filtered; the residue was submitted to a further treatment which will be given below and which proved that no uranium was contained in it. The mineral solution was evaporated to dryness, the residue was moistened with nitric acid, treated with hot water and dissolved. A very slight residue was left undissolved; it consisted of silica and was added to the first residue. The filtrate was treated with an excess of hydrogen sulphide and the sulphides removed. A current of air was passed through the solution to expel the excess of hydrogen sulphide; the solution was heated to boiling and oxalic acid added. The precipitation was immediate and abundant. The next day the oxalates were filtered off; the solution was heated, 2 grams of thorium nitrate were added and precipitated again with an excess of oxalic acid. The oxalates were removed after some hours and added to the first precipitated oxalates. They were gently ignited to form the oxides and further heated with sulphuric acid. The sulphates formed were dissolved in water and the hydroxides precipitated five times. The final precipitate was dissolved in dilute hydrochloric acid and brought into a glass bulb where the growth of radium could be tested from time to time: main solution from Bröggerite.

TABLE 6.

Growth of radium in the main solution from Bröggerite 1.

Test	Time from start in days	Radium emanation found expressed in terms of radium	Growth of radium per day
1	2·82	$0·874 \times 10^{-9}$	
2	212·	$11·730 \times 10^{-9}$	$0·0467 \times 10^{-9}$
3	279·	$14·961 \times 10^{-9}$	$0·0470 \times 10^{-9}$
4	311·	$16·526 \times 10^{-9}$	$0·0470 \times 10^{-8}$
5	318·	$16·886 \times 10^{-9}$	$0·0471 \times 10^{-9}$
6	324·	$17·158 \times 10^{-9}$	$0·047 \times 10^{-9}$

Average growth of radium is $0·047 \times 10^{-9}$ gram.

The radium present in the solution at the start was $3·0 \times 10^{-9}$ gram.

The solution from which the oxalates had been removed was evaporated to dryness and ignited in order to destroy the oxalic acid. The residue was dissolved in nitric acid and a solution containing two grams of oxides of rare earths from gadolinite

was added. The solution was now heated and hydrofluoric acid added. The fluorides were treated as already told for cleveite and a second solution for measuring the growth of radium was obtained: test solution from bröggerite.

TABLE 7.

Growth of radium in test solution from Bröggerite 1.

Test	Time from start in days	Radium emanation found expressed in terms of radium	Growth of radium per day
1	4.	0.129×10^{-9}	
2	97.	0.265×10^{-9}	0.0002×10^{-9}
3	226.	0.347×10^{-9}	0.0004×10^{-9}

Here is perhaps a very small augmentation of radium; in every case it does not amount to as much as one per cent.

The average growth of radium is

$$\begin{aligned} &\text{per day: } 0.047 \times 10^{-9} \text{ gram} \\ &\text{or per year: } 17.155 \times 10^{-9} \text{ gram} \end{aligned}$$

The amount of radium in 200 grams of mineral was found to be 4.07×10^{-5} . The constant of change of radium then is

$$\frac{17.16 \times 10^{-9}}{4.07 \times 10^{-5}} = 4.22 \times 10^{-4} \text{ (year)}^{-1}$$

and the half-value period is

$$\left(\frac{\log_e 2}{4.22 \times 10^{-4}} \right) 1642 \text{ years.}$$

The residue insoluble in nitric acid weighed about 5 grams and had an activity corresponding to 2 grams of mineral. It was treated with hydrofluoric acid, then evaporated to dryness with sulphuric acid. To the residue was added hydrochloric acid; and the solution filtered off; it contained no uranium; the residuum still had the initial activity; it was boiled with an excess of sodium bicarbonate and filtered; the undissolved part was treated with hydrochloric acid, which dissolved the small amount of carbonates found. Neither did this solution contain any uranium. The residue, now nearly inactive, consisted chiefly of niobic and tantallic acid; it was treated with hydrofluoric acid which dissolved a large part of it. The remaining part 0.9 gram only had a very slight activity and consisted, I think, chiefly of unattacked columbite.

4. Ionium solution from Bröggerite 2, Norway.

This bröggerite was a very pure sample from the same locality as the first one—Raade in Norway; it was given to me by

the Institute of Mineralogy of the University in Kristiania and I am glad to have here an opportunity to express my gratitude.

100 grams of the pulverized mineral were brought into solution in nitric acid. The residue weighed 3.4 gram and a treatment with hydrofluoric acid and sulphuric acid removed the silica and reduced it to 2.4 grams. It was now melted with an excess of potassium hydrosulphate. The mass was boiled with water and filtered; the solution contained no uranium; a precipitate obtained with ammonia was dissolved in nitric acid and added to the main solution.

The residue undissolved in boiling water was treated with hydrochloric acid, which dissolved the niobic and tantallic acid. The slight residue was boiled with sodium bicarbonate in excess and filtered. To the undissolved part was added dilute hydrochloric acid; only 0.2 gram was left and its activity was negligible.

To the solution of the mineral was added hydrogen sulphide and the sulphides removed exactly as given under Bröggerite 1. When the excess of hydrogen sulphide was expelled the solution was heated to boiling in a platinum dish and hydrofluoric acid was added. The liquid was allowed to cool and the fluorides were filtered off. A solution of three grams of oxides of rare earths was added to the mineral solution and again precipitated as fluorides and removed. All the fluorides were converted into sulphates by the ordinary manipulations. The sulphates were dissolved in water and the hydroxides were precipitated five times. The final precipitate was dissolved and brought into a glass bulb as Sol. 1. The results of the measurements are given in Table 8.

TABLE 8.

Growth of radium in the main solution from Bröggerite 2.

Test	Time from start in days	Radium emanation found expressed in terms of radium	Growth of radium per day
1	4.	0.224×10^{-9}	
2	68.	1.826×10^{-9}	0.0231×10^{-9}
3	140.	3.623×10^{-9}	0.0241×10^{-9}

Average growth of radium per day, 0.0236×10^{-9} gram.

The radium present in the solution at the start was :

0.40×10^{-9} gram.

To the solution from which the fluorides had been removed a new quantity of rare earths was added and again precipitated as fluorides. These fluorides were treated exactly like the

main precipitate and the solution finally obtained was brought into a glass bulb.

The results of the measurements will be found in Table 9.

TABLE 9.

Growth of radium in test solution from Bröggerite 2.

Test	Time from start in days	Radium emanation found expressed in terms of radium	Growth of radium per day
1	1·83	$0·022 \times 10^{-9}$	
2	138·	$0·070 \times 10^{-9}$	0·00

This solution shows no augmentation of radium and consequently contains no ionium.

For the main solution from bröggerite 2 only two results are yet obtained. As average growth of radium I shall give here the mean value between these two results; but I expect to make some more measurements later on.

The average growth of radium

per day is: $0·0236 \times 10^{-9}$ gram.

“ year is: $8·614 \times 10^{-9}$ gram.

The amount of radium in 100 grams of mineral has been found to be $2·08 \times 10^{-5}$ gram.

The constant of change of radium then is :

$$\frac{8·614 \times 10^{-9}}{2·08 \times 10^{-5}} = 4·14 \times 10^{-4} \text{ (year)}^{-1}$$

and the half-value period is :

$$\frac{0·693}{4·14 \times 10^{-4}} = 1674 \text{ years.}$$

The results obtained from the first two minerals, uraninite from N. Carolina and cleveite from Norway, indicate clearly that the constant of change of radium has a higher value than the one generally accepted— $3·48 \times 10^{-4} \text{ (year)}^{-1}$. Neither of them, however, can claim a very high degree of accuracy for the reasons already given. But so far as I can understand no objection can be raised against the results from the two samples of bröggerite. The two solutions have been prepared at different times and in a different manner; the radium content in one of them is nearly twice as large as in the other. But the rate of change calculated from the radium present and the radium formed has the same value in both cases.

I have asked myself if any particular objection may be raised against the use of bröggerite, but I do not think this possible. The mineral is certainly one of the oldest uraninites

and it is particularly free from all alteration products. It is true that it contains some thorium; in the way I determine the radium content some thorium emanation may be brought into the electroscope with the radium emanation. I have sometimes observed, that the current was higher the minute the emanation was brought into the electroscope, than ten minutes later. But the measurements are always taken three hours later, when the current due to the radium emanation has reached its maximum value, and during the same period the thorium emanation has died away. Further, I have often demonstrated that the activity of the active deposit from thorium can not have influenced the results. Three hours after the removal of the emanation, practically no activity is left in the electroscope, and after 12 hours *no* trace whatever of activity can be detected.

It would certainly be of interest to confirm the result obtained from bröggerite by using other minerals.

Conclusions.

The growth of radium in solutions of ionium preparations separated from different uranium minerals has been measured. The results obtained for the most carefully prepared solutions are: The disintegration constant of radium has a value of

$$\begin{array}{l} 4.22 \times 10^{-4} \text{ (year)}^{-1} \\ \text{and} \quad 4.14 \times 10^{-4} \text{ (year)}^{-1} \end{array}$$

The half-value period of radium indicated is accordingly: 1642 years and 1674 years. The result agrees very closely with the value found by Sir Ernest Rutherford.

In concluding, I wish to express my thanks to Mr. Boltwood for the kindness with which he received me in his laboratory, for his interest in the work and his many valuable suggestions.

The work described in this paper was made possible through the fact of my receiving a fellowship from the American Scandinavian Foundation. I desire to express here my appreciation of their generosity.

Kristiania, Norway, October 11, 1915.

ART. IV.—*Some New Mineral Occurrences from the Tintic District, Utah*; by A. H. MEANS.

THE following paper is a brief account of some of the work done at the Geological Laboratory of the Massachusetts Institute of Technology, in connection with the forthcoming U. S. Geological Survey Report by Professor W. Lindgren upon the Tintic Mining District of Utah. Several minerals heretofore unreported in the district were found, together with one not previously noted in the United States, and another which is believed to be a new mineral species.

GEOCRONITE,* (?) $5\text{PbS} \cdot \text{Sb}_2\text{S}_3$.—This specimen comes from the 300-foot level of the Colorado mine, and consists essentially of galena, anglesite and cerussite, together with small amounts of quartz, zincblende, chalcocite and covellite. In polished section, upon etching with HCl (1:1), fine fingering veinlets of an unetched metallic mineral were seen in the galena. Some of this unetched material gave an antimony test in closed tube and a lead coating on coal, showing the mineral to be a sulphantimonite of lead. A specimen of stibnite was polished and compared with the sulphantimonite of lead upon the possibility that the lead noted was due to adhering galena and not to the mineral itself. Micro-chemical tests upon the two specimens did not correspond however. The mineral gave the following micro-chemical reactions which are typical of geocronite:†

HCl (1:1), no reaction. HCl (concentrated), instantly, bright brown then iridescent. HNO_3 (concentrated), mineral blackens with slight effervescence, and finally is covered by a white coating. KOH, no reaction. KCN, no reaction.

The mineral was also compared with a sample of pure geocronite with which it corresponded in chemical and physical properties, leaving little doubt as to the identity of the mineral.

ADAMITE,‡ $4\text{ZnO} \cdot \text{As}_2\text{O}_5 \cdot \text{H}_2\text{O}$.—This mineral comes from the No. 3 shaft, Iron Blossom mine. The specimen consists principally of the limonite, upon which are greenish white tabular crystals the majority of which form radiate groups and rosettes. Under the microscope, the crystals were seen to be tabular in form, showed parallel extinction and low birefringence, and practically disappeared in a solution having refractive index of 1.73. In closed tube with dried soda and charcoal a strong arsenic mirror was obtained. In closed tube alone water was

* Dana's System of Mineralogy, 6th Edition, p. 143, 1911.

† From a manual of micro-chemical tests, now in the press, by Joseph Murdock of the Geological Department of Harvard University.

‡ Determined independently, some months previous to the author's determination, by W. L. Whitehead of the Massachusetts Institute of Technology.

Dana's System of Mineralogy, 6th Edition, p. 786, 1911.

given off. On coal a zinc coating appeared after heating before the blow-pipe. Lead, iron, calcium and magnesium were tested for, and were found to be absent.

This occurrence is interesting because, so far as the author is aware, it is the first time adamite has been found in the United States. The other localities from which this mineral is reported being: Chañarcillo, Chile; Cap Garonne, France; and in the ancient zinc mines of Laurium, Greece.*

DAUBRÉEITE,† (?) $2\text{Bi}_2\text{O}_3 \cdot \text{BiCl}_3 \cdot 3\text{H}_2\text{O}$.—The specimen comes from the 1200-foot level of the Eagle and Blue Bell mine, and for the most part is composed of quartz, barite, cerussite, together with some alunite, jarosite, daubréeite (?) and bismite (?). Upon this specimen there occurred rosettes of small yellow-brown crystals of brilliant luster. In habit they appeared to be slender prisms of hexagonal cross-section, surmounted by truncating faces. The mineral was partially soluble in water, the solution reacting strongly for chlorine. A strong bismuth reaction was also obtained in the wet way.‡ Water was given off in the closed tube, together with a very faint white sublimate which may be PbCl_2 . The only definite tests obtained were for chlorine, water and bismuth. The mineral is certainly a hydrous bismuth chloride and as daubréeite is the only such listed in Dana,§ it is reasonable to conclude that the mineral is either daubréeite or a new species. Unfortunately the supply of material was limited and there is not enough of it remaining for additional tests.

BISMITE,|| (?) Bi_2O_3 , and JAROSITE,¶ $\text{K}_2\text{O} \cdot 3\text{Fe}_2\text{O}_3 \cdot 4\text{SO}_3 \cdot 6\text{H}_2\text{O}$.—Upon another portion of the same specimen described under the heading daubréeite there occurred a yellowish-brown friable material which gave the following tests:

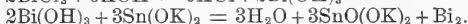
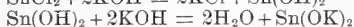
A strong bismuth reaction, both in the wet way and on charcoal. Magnetic after heating on charcoal. Soluble in HCl without effervescence. No arsenic with soda and charcoal in closed tube. Water in closed tube. Strong sulphate test. Very slight chlorine test. Faint lead test.

Under the microscope, light yellow-brown hexagonal prisms, the bases of which were divided in six segments, were seen. The form is typical of jarosite. This coupled with the miner-

* Loc. cit., p. 787.

† Loc. cit., p. 174.

‡ Treadwell and Hall, 2d Edition, p. 166, 1908. The Bi-test is as follows: To a few drops of SnCl_2 add strong KOH till the precipitate formed just dissolves. To this solution add a hydrochloric acid solution of the substance to be tested. If bismuth is present a black precipitate of metallic bismuth will form instantly. The reactions are:



§ Dana's System of Mineralogy, 6th Edition, p. 174, 1911.

|| Loc. cit., p. 200.

¶ Loc. cit., p. 974.

alogical tests definitely determines the crystalline material as jarosite. Jarosite has been previously noted in the Tintic district.* The remaining material is not crystalline, being pulverulent and earthy. From the strong bismuth reaction obtained and the absence of effervescence with HCl, which is typical of bismutite, this material is believed to be bismite. The nature of the occurrence is such, however, as to make absolute proof impossible without a chemical analysis.

BISMUTITE,† $\text{Bi}_2\text{O}_3 \cdot \text{CO}_2 \cdot \text{H}_2\text{O}$.—This occurrence is from the 1050-foot level of the Victoria mine, and consists principally of barite and quartz containing argentite, horn-silver, bismutite and a little native gold. The bismutite was seen in polished section as thin dark veinlets between the argentite and the gangue. Upon treating with HCl, under the microscope, the material was seen to effervesce, the solution giving a positive test for bismuth. An analysis of this material by Dr. R. C. Wells of the U. S. Geological Survey gave:

Loss on ignition	3.57
Insoluble in HNO_3	66.10
Soluble in HNO_3	
CO_2	2.48
Cl	0.
As_2O_505
P_2O_5	0.
Cu	0.
Ag	4.15
PbO31
Fe_2O_392
CaO76
MgO	0.
Bi_2O_3	18.07
SO_358
	<hr/>
	96.99

Another occurrence of bismutite is from the bottom of the winze on the 12th level of the Eagle and Blue Bell mine. Here straw-yellow crusts occur on a specimen consisting essentially of argentite and horn-silver with a little native gold, the specimen being very similar to the one from the Victoria mine described above. The crusts are non-crystalline and effervesce freely in cold dilute HCl, the solution giving a definite bismuth test.

Bismutite has also been found in considerable amount in the Boss Tweed mine, where it occurs with quartz and barite.‡

ARSENO-BISMITE, a new bismuth arsenate.—This specimen came from the 600-foot level of the Mammoth mine, where it

* Tower and Smith, U. S. Geological Surv., 19th Ann. Rept., p. 702, 1898.

† Loc. cit., p. 307.

‡ Tower and Smith, U. S. Geological Surv., 19th Ann. Rept., p. 703, 1898.

occurs in large amounts, and consists of a heavy yellow friable material, which is believed to be a new mineral species, limonite, barite, and a little erinite and mixite. In closed tube with soda and charcoal a heavy arsenic mirror was obtained, while on coal before the blowpipe a large yellow coating of bismuth oxide appeared. About half a kilogram of the material was crushed in a mortar and put through 80-mesh, then vanned on a vanning shovel, about 30 grams of concentrates being obtained. The concentrates were examined, under the microscope, and seen to contain a yellowish-brown mineral in crystalline aggregates, considerable barite and 2.0 per cent (estimated by micrometric methods) limonite. Some of these concentrates were treated with hot HCl, and the residue, which was examined under the microscope, was seen to consist solely of barite, everything else having gone into solution. An analysis of the concentrates by Dr. R. C. Wells of the United States Geological Survey is given below :

Insoluble in HCl:

SO ₃		16.60	}	49.92
BaO	(calculated)	31.90		
SiO ₂	(difference)	1.42		

Soluble in HCl:

Bi ₂ O ₃	-----	28.17
As ₂ O ₃	-----	10.59
Fe ₂ O ₃	-----	3.88
Al ₂ O ₃	-----	.44
CuO	-----	.12
CaO	-----	.62
MgO	-----	tr.
SO ₃	-----	.46
H ₂ O -	-----	1.09
H ₂ O +	-----	1.43
P ₂ O ₅	-----	.04
Sb ₂ O ₃	-----	1.26
PbO	-----	1.12
		<hr/>
		99.14

A determination of hygroscopic water was made by the author by placing a weighed sample in a desiccator containing strong sulphuric acid which had previously been heated to boiling to expel all water. The sample was kept in this desiccator until constant weight was obtained, which required about three weeks. The loss in weight was 0.38 per cent, and may perhaps be considered as representing hydroscopic water, the water remaining being water of crystallization.

Considering now the molecular ratios, from which the 0.38 per cent water has been deducted, there result :

	Per cent	Molecular ratio
Bi_2O_3	28.17	0.061
As_2O_5	10.59	0.046
Fe_2O_3	3.88	0.024
Al_2O_3	0.44	0.004
CuO	0.12	0.002
CaO	0.62	0.001
SO_3	0.46	0.006
H_2O	2.14	0.119
P_2O_5	0.04	0.000
Sb_2O_3	1.26	0.004
PbO	1.12	0.005

From the mineral association as observed in the district the following minerals were assumed to be present and the molecular ratios representing them deducted. They are: anglesite, PbSO_4 ; mixite, $20\text{CuO} \cdot \text{Bi}_2\text{O}_3 \cdot 5\text{As}_2\text{O}_5 \cdot 22\text{H}_2\text{O}$; limonite, $2\text{Fe}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$ (2.0 per cent present as previously mentioned) and jarosite. The remaining Fe_2O_3 , CaO , Sb_2O_3 , Al_2O_3 , are considered isomorphous with the Bi_2O_3 .

There now remain :

Bi_2O_3	0.061	}	0.092	2.0
Fe_2O_3	0.012			
CaO	0.011			
Sb_2O_3	0.004			
Al_2O_3	0.004			
H_2O	0.098		0.098	2.1
As_2O_5	0.046		0.046	1.0

This gives a formula of $2\text{Bi}_2\text{O}_3 \cdot \text{As}_2\text{O}_5 \cdot 2\text{H}_2\text{O}$.

Considering now, as an alternate formula derived by assuming all the water as water of crystallization, i. e., including the 0.38 per cent water previously mentioned as hygroscopic moisture, there result :

Bi_2O_3	1.561	}	0.092	4.
Fe_2O_3	0.012			
CaO	0.011			
Sb_2O_3	0.004			
Al_2O_3	0.004			
H_2O	0.119		0.119	5.2
As_2O_5	0.046		0.046	2.

This changes the previous formula to the following $4\text{Bi}_2\text{O}_3 \cdot 3\text{As}_2\text{O}_5 \cdot 5\text{H}_2\text{O}$. Either formula appears to fit the data equally well, depending upon the manner in which the question relating to hygroscopic water and water of crystallization is decided.

The properties of the mineral may be briefly described as follows: Color—yellowish green with tinge of brown. Habit—cryptocrystalline aggregates. Hardness—not determined because of pulverulent condition of the sample. Probably about 3.0. Specific gravity—5.70 as determined by pycnometer.

Index—several crystalline aggregates were matched against a solution having a refractive index of about 1.60.

The only other bismuth arsenates recorded in Dana are atelestite* and rhagite.† The former occurs very sparingly on bismutoferrite, a bismuth-iron silicate, associated with erythrite, cobalt bloom, at the Neuhihle mine, Schneeberg, Saxony. The latter is found on bismutite and quartz accompanied by walpurgite, a basic arsenate of uranium and bismuth, at the Weisser Hirsch mine, Neustädtel, near Schneeberg, Saxony. These, however, occur in but limited amounts and from the description appear to be of interest more as mineralogical curiosities than for any other reason.

For purposes of comparison the properties of atelestite, rhagite and the mineral described in this paper are given below:

	Atelestite	Rhagite	New mineral
<i>Specific gravity</i>	6.4	6.82	5.70
<i>Hardness</i>	3-4.5	5.	? (about 3.)
<i>Habit</i>	monoclinic	crystalline aggregates	crystalline aggregates
Bi_2O_3	83.9	78.8	77.7
As_2O_5	13.9	15.7	19.3
H_2O	2.2	5.5	3.0
<i>Color</i>	Sulphur-yellow	yellowish green	yellowish green

The formulas are as follows: Atelestite, $3\text{Bi}_2\text{O}_3 \cdot \text{As}_2\text{O}_5 \cdot 2\text{H}_2\text{O}$; rhagite, $5\text{Bi}_2\text{O}_3 \cdot 2\text{As}_2\text{O}_5 \cdot 9\text{H}_2\text{O}$; new mineral, $2\text{Bi}_2\text{O}_3 \cdot \text{As}_2\text{O}_5 \cdot 2\text{H}_2\text{O}$.

Summary.—From the above data it is seen that the material described is homogeneous and of uniform chemical composition. Unlike atelestite and rhagite, which are of sparing occurrence, it occurs in considerable amounts, the material being a considerable part of a new stope opened up on the 600-foot level of the Mammoth mine, and assaying 3 to 19 per cent copper, one ounce gold, 150 ounces silver, and 18 to 35 per cent bismuth.‡ While it is desirable that additional analyses be made of new material it is nevertheless reasonable to conclude the substance is a definite mineral having a definite composition, which the formula given above approximates very closely, if it does not give it exactly. It is quite possible that a number of bismuth arsenates exist as is the case with copper.

In view of these facts it seems desirable that the mineral be provided with a name, for which *arseno-bismite* has been suggested as conveying better than any other an idea of its chemical composition.

Geological Department, Mass. Inst. of Technology, Boston, Mass.

* Loc. cit., p. 804.

† Loc. cit., p. 860.

‡ Min. Sci. Press, cix, No. 12, p. 463.

ART. V.—*The Present Status of the Investigation of the Origin of Barrier Coral Reefs*; by THOMAS WAYLAND VAUGHAN.*

[A preface to "Relations of Coral Reefs to Crust Movement in the Fiji Islands," by E. C. Andrews.]

As the paper by Mr. Andrews, which follows this, has an important bearing on the theory of the formation of coral reefs, it seems appropriate that it should be preceded by a sketch of the principal hypotheses advanced to account for such structures and a brief résumé of the results of some of the more recent studies.

The history of coral reef theory is usually dated from the appearance of Darwin's "Structure and distribution of coral reefs" in 1842, although he had previously announced his views in 1837, and important and astute observations on corals and coral reefs had been published by Chamisso as early as 1821. As the views of Dana, based upon his observations made while on the Wilkes Exploring Expedition and published in 1849, accorded with those of Darwin, the hypothesis advanced by the latter and supported by the former is generally known as the Darwin-Dana hypothesis. According to it barrier reefs and atolls are to be explained by corals first forming a fringing reef on the sloping shore of a subsiding land area; the reef grows upward at such a rate that its top remains near the surface of the water and through the retreat of the shore it is converted into a barrier; continued subsidence where the inclosed land-area is an island may result in the production of an atoll circumscribing a lagoon without any land mass projecting above the water level. It should be emphasized that this hypothesis involves more than mere subsidence and the conversion of a fringing into a barrier reef. It also attempts to account for extensive submarine platforms by assuming that they have been built upon sloping basements behind barrier reefs through agencies dependent on the presence of corals.

The first important protest against this hypothesis was made by Carl Semper, who, in 1863, after studies in the Pelew Islands, published the opinion that atolls could be formed in areas of elevation by the solution of the interior of pre-existent masses of limestone, and that solution, erosion by currents, and wave-cutting might develop platforms behind fringing reefs. Subsequent to Semper, the students of the coral reef problem arrayed themselves in two camps, one of which supported while the other opposed the interpretations of Darwin and Dana. Among the most important opponents

* Published by permission of the Director of the United States Geological Survey.

were Sir John Murray, Admiral Sir W. J. L. Wharton, Alexander Agassiz, and Stanley Gardiner.

Murray introduced the idea of banks being built upward by showers of the remains of pelagic organisms until the bathymetric zone of reef-forming organisms is reached, and he called attention to the cutting of volcanic islands down to wave base. According to his hypothesis as summarized by himself, "when coral plantations grow up from submarine banks they assume an atoll form owing to the more abundant supply of food to the outer margin and by the removal of dead coral from the interior portion by currents and *by the action of carbonic acid gas dissolved in sea water,*"* and "that the barrier reefs have been built out from the shore on a foundation of volcanic debris or on a talus of coral blocks, coral sediment, and pelagic shells, and that the lagoon channel is formed in the same way as a lagoon." In Wharton's opinion the uniform depth of the atoll lagoons in the Pacific is to be explained by corals growing upon the bases of volcanic islands which have been reduced by wave action to wave base. Agassiz, besides accepting in principle the views of Semper, Murray, and Wharton, ascribed the formation of the platforms of barrier reefs to marine erosion without change of sea level. Stanley Gardiner, whose opinions are closely in accord with those of the investigators mentioned, believes submarine planation effective to a depth as great as 200 fathoms.

Other investigators were obtaining results which, although partly accordant with it, were really leading to an important modification of the Darwin-Dana hypothesis. Andrews pointed out that the platform of the Great Barrier Reef of Australia has been depressed in Recent geologic time, that it continues southward of the reef, and that only a minor part of it is formed of coral growth. Hedley and Griffith Taylor, who also studied the Great Barrier Reef, accepted the essentials of the interpretation of Andrews and showed that coral reefs of either atoll or linear form, which rise above shallow platforms, owe their shapes to prevailing winds and currents. Daly noted the accordance in the depths of drowned valleys around the islands within barrier reefs, in the barrier reef lagoon channels, and in the atoll lagoons of the Pacific, and attributed this accordance to Recent rise of sea level subsequent to deglaciation whereby the depth of water in the tropics was increased some 20 to 30 fathoms, thereby submerging antecedent platforms of marine planation.

This brief review of the leading coral reef theories leads to the formulation of the questions: (1) Can a lagoon be formed through submarine solution by sea water; (2) what is the rela-

* Not italicized in the original.

tion of barrier reefs to the last dominant change in the position of strand line; (3) are the reefs superposed on antecedent platforms or are the platforms which the reefs margin or above which they rise due to infilling and leveling behind reefs? The following indicates the present status of information on these subjects:

1. Recent investigations conducted in Florida show not only that submarine solution is not effective there, as all the bays, sounds, and lagoons are being filled with sediment, which is largely a bacterial precipitate as shown by the investigations of Drew and Kellerman, but that according to analyses made by Dole there is no free CO_2 in the sea water. These results accord with the conclusions reached by numerous investigators in the Pacific, which are that the more or less continuous walls inclosing lagoons have been formed by constructional geologic processes and that lagoon channels and atoll lagoons are not due to submarine solution.

2. Nearly all if not all the off-shore reefs in the western Atlantic Ocean, the Caribbean Sea, and the Gulf of Mexico have been investigated and, with the possible exception of the reef off the southeast coast of Barbados, it is established that they have been formed either during or subsequent to submergence. This is in accord with the results obtained in the Pacific by Dana, Andrews, Hedley and Griffith Taylor, and P. Marshall, and more recently by W. M. Davis.

3. R. T. Hill was apparently the first to recognize the relations of living reefs to submerged terraced surfaces. After describing the elevated reefs of Jamaica, he says that "Jamaica was once a more extensive land area than now with benched and terraced margins which were submerged by subsidence" and that "similar submerged plains are now occupied by the growing reefs around the island." Andrews, in his article which follows, gives the results of his studies of the Great Barrier Reef of Australia, published in 1902, and of his investigations in the Fiji Islands.* After long continued studies in Florida, in the Bahamas, in areas in Central America, and in a number of the West Indian Islands, I will say that the modern off-shore coral reefs of the western Atlantic Ocean, the Gulf of Mexico, and the Caribbean Sea have grown upon antecedent platforms, often on terraced surfaces, either during or after submergence, where conditions are favorable for the life of such reef-forming organisms.

*It is gratifying to me that Mr. Andrews has essentially confirmed a statement I published in 1914, which is that "a study of the charts of barrier reef islands, as Viti Levu, Fijis, and Tahiti, Society Islands, show that the platforms are independent of the presence of reefs, and therefore the relations in these islands are similar to those indicated for barriers off continental shores, for here the reefs are also superimposed on platforms antedating their presence."

The detailed investigations so far made have substantiated two of the Darwin-Dana contentions, which are: (1) that off-shore reefs have formed either after or during submergence; (2) that the lagoon channels inside barrier reefs and atoll lagoons owe their origin to constructional geologic agents which have built up more or less interrupted inclosing walls. In a third relation, however, the results are not in accord with their hypothesis, for the platforms which the reefs margin or on which they grow, wherever adequately investigated, have been shown to antedate the development of the reefs, and that reefs have formed on such basements, during or after submergence, where the necessary ecologic conditions prevail. The Grand Banks of Newfoundland, the banks off the coast of Nova Scotia, and Georges Bank off Cape Cod, are instances of recently submerged platforms which would furnish proper habitats for reef-building corals did they not lie outside the life zone of such organisms; while the Floridian Plateau, Campeche Bank off Yucatan, and Mosquito Bank off Nicaragua and Honduras, which lie within the life zone of such organisms, support many reefs.

The origin of the different platforms and the cause of their submergence must now engage the attention of the students of these problems. Andrews has made two notable contributions to our knowledge of the origin of the platforms in his work on the Great Barrier Reef and in that on the Fijis; and Professor Pirsson has made one of great value in his account of the geology of Bermuda Island. Much attention has been paid to these relations in Florida and in some of the West Indian islands. The relations in the last mentioned islands are complex and can not be expressed in a single formula. The basements, which are fundamentally due to structural and constructional geologic processes, have been subjected to the action of subaerial and submarine planation processes during many changes in the position of the strand line. Some reefs, as those off the eastern end of Porto Rico and those off Virgin Gorda, are growing on what was a land surface only a short time ago, while others, as the one off the south side of St. John Island, appear to have grown upward on a submarine plain which has recently undergone deeper submergence.

The investigation of the causes producing submergence is only in a preliminary stage. That local differential crustal movement has been important in producing Recent change in the position of strand line in coral reef areas is certain. Daly has ably presented the evidence in favor of another factor, which is that through deglaciation there has been increase in volume of oceanic water and a consequent rise of sea level in the tropics; and Barrell has helped in the formulation of the

problem by his article, "Factors in movements of the strand line and their results in the Pleistocene and post-Pleistocene."* As so large a proportion of present day shore lines shows evidence of submergence, it appears that the phenomena can not be explained by appeal to local causes alone or to deglaciation as the only general cause, but that there must have been some diastrophic change in the earth which has resulted in the sea overflowing the marginal land areas in geologically Recent time. Although persistent investigation of shore-line phenomena may render possible the discrimination of effects which may be due to general from those which may be due to local causes, it is probable that the understanding of whatever general causes there may be is conditioned on advance in knowledge of the physical history of the earth.

ART. VI.—*Relations of Coral Reefs to Crust Movements in the Fiji Islands*; by E. C. ANDREWS,† Sydney, New South Wales.

IN 1898, the writer, in company with Mr. B. Sawyer, now Superintendent of the Mount Lyell Copper Mine, Tasmania, made certain geological observations in eastern Fiji on behalf of the late Professor Alexander Agassiz. The results of the work, together with a preface by Professor T. W. Edgeworth David, of Sydney University, were published under the title of "Notes on the Limestones and General Geology of the Fiji Islands, with special reference to the Lau Group" in the Bulletin of the Museum of Comparative Zoology, at Harvard College, vol. xxxviii, 1900, with 39 plates.

The general conclusions reached in that report for the eastern islands of Fiji were that the whole of the group had been built upon a submarine platform consisting, in part, of volcanic rocks upon which bedded limestones and volcanic ash had been deposited; that these beds had been tilted, forming islands; and that, at a later period, the eastern islands of the group had been elevated, with pauses, during which fringing coral reefs

* This Journal (4), vol. xl, pp. 1-22, July, 1915.

† The article immediately preceding this has been prepared in response to the request of the editor, that I write a brief introduction to Mr. Andrews' article so that its bearing on coral-reef theory might be obvious to those who have not a detailed acquaintance with the widely-scattered literature on the subject. An attempt was made to convey the desired information in one or two paragraphs, but as the subject is complex that was not practicable.

had grown out from the islands, giving them a terraced appearance after elevation.

After the elevation of the limestones and ash beds, it was considered that a volcanic outburst had taken place, causing the intrusion by igneous rocks, in part, of the raised limestones and ash beds.

In the following year, 1899, while the writer was conducting a geological survey in New England, New South Wales, he found himself at a loss to account for the existence of certain common but striking topographical features in that region. During that year, also, the works of certain American physiographers were perused carefully by him for the first time. Having grasped the main principles of modern physiography by such study, an excursion was made with Mr. C. Hedley, in 1901, to the Great Barrier Reef of North Queensland, and it became apparent at once that the origin of this Great Barrier Reef would be best interpreted by a study of the associated land forms, and two essays were published to set forth the results of these observations* made both in New England and in Northern Queensland.

In these regions it was found that a peneplain had been uplifted, in stages, to great heights above sea level; that profound gorges had been excavated therein by running streams, and that the coastal region had been broadly degraded while gorges had been cut by the inner, or headward, portions of the streams; that at a late stage in this degrading process, the coastal region had been submerged for hundreds of feet, the sea thus trespassing far across the coastal lowlands so as to convert a strip of these coastal lowlands into a portion of the continental shelf, dotted with hilly or mountainous islands. Inasmuch as the area now occupied at present by the Great Barrier itself, and the associated fringing reefs, around the islands, presumably participated in the movement of submergence, the present Barrier Reef, and the associated reefs, indicated a growth upwards of 'coral-reef' organisms, both during and after submergence. Signs of a more recent, but slight, emergence were found in the form of masses, *in situ*, of the Great Barrier Reef, lying a few feet above high-water mark, in flats of alluvium also occurring from five to twenty feet above high-water mark and showing recent stream dissection, as also in wave-cut platforms in granites and contorted sediments alike occurring a few feet above high-water mark.

The idea was thus strongly suggested that although the elevation of a peneplain to heights, in places, exceeding 4,500

* E. C. Andrews, Notes on the general geology of the Queensland Coast, Proc. Linn. Soc., N. S. Wales, 1902, pp. 146-185.

Id. The Tertiary History of New England, N. S. Wales, Records Geol. Survey, N. S. Wales, 1903, pp. 140-216, plates XXXI to XLI.

feet above the sea, and the deep dissection by streams of the uplifted peneplain, were the main activities which had determined the present topography of the mainland, nevertheless the Great Barrier Reef of Australia, as it appears to-day, has resulted from the growth, upwards and outwards, of coral-reef organisms, upon a submerged portion of the coastal area. This coastal submergence is of recent date.

This is in accordance with the general principles of Barrier Reef origins laid down by Darwin and Dana. Jukes also considered that Darwin's explanation of the Great Barrier Reef of Queensland was the most satisfactory supplied to date.*

Professor Alexander Agassiz, however, considered that the action of subsidence had been called in unnecessarily by these writers.†

In his opinion the coastal portions of the recent Queensland area had been cut by the waves to the condition of a submarine platform, and that coral and other reef-building organisms had grown upon "the terraces of erosion" to which the coastal area had been reduced thus, and by the coalescence of coral masses once isolated, the Great Barrier Reef had been formed.

In the Fiji Report of 1899 by the writer, sufficient account was not taken of coral-reef formation during submergence whereas, at a later period, the writer was compelled to regard submergence as essential in the formation of the Great Barrier Reef of Queensland. On this account a revision of the Fiji work was made from memory to ascertain whether submergence might not have been operative there also. Not having had the chance to reexamine the Fiji Islands since the report of 1899 was made, it has been deemed advisable to reopen the case for submergence in Fiji, merely as a possible, or rather probable, alternative to the published statement.

The accompanying brief notes on several islands in the Fiji Group may suffice to make the case intelligible (see accompanying map).

Viti Levu, the main island of the Fiji Group, is about 4,500 square miles in area.‡ Strong streams draining the island rise in high plateaus, thence they enter upon torrent tracks between high ranges, while still lower down stream they flow through deep wide valleys, finally entering the sea as long ramifying salt water arms often dotted with islands and occupied by del-

* Voyage of H. M. S. "Fly," vol. i, pp. 333-347.

† A. Agassiz, "Great Barrier Reef of Australia," Bull. Mus. Comp. Zool. Harvard College, xxviii, p. 110, 1898.

‡ For a general description of the structure of the Viti Levu two papers by W. G. Woolnough might be consulted with advantage.

The Continental Origin of Fiji, General biology, Proc. Linn. Soc., N. S. W., vol. xxviii, p. 457, 1903.

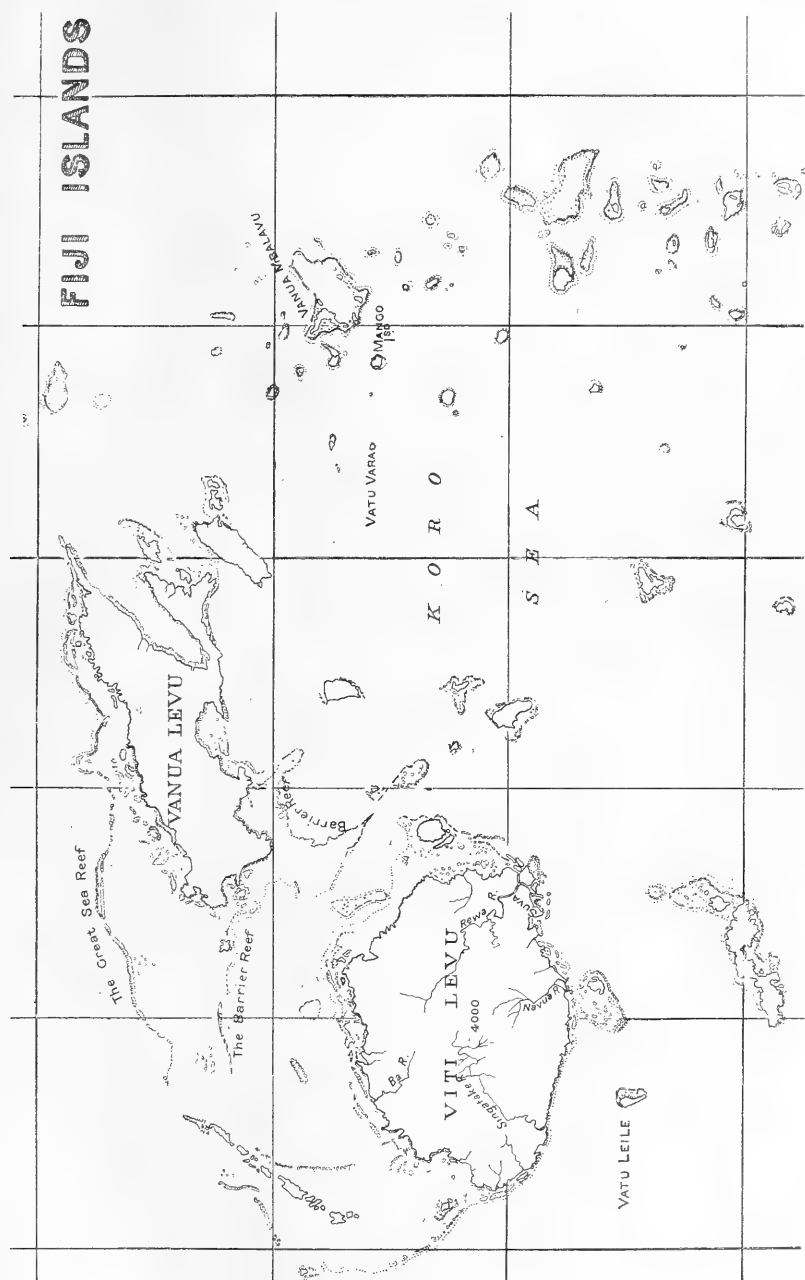
tas at their heads. Moreover, these salt water arms occupy the lower portions of valleys which belong to the type now universally admitted to be formed by ordinary stream action. The Viti Levu salt water arms, therefore, with their contained deltas suggest the submergence of the Viti Levu coastal lowlands in recent time, with the consequent drowning of the lower portions of the river courses.

The island is girt with a Great Barrier Reef, several hundreds of miles in length, broken here and there by passages. The present Great Barrier Reef, which rises to the level of the sea, has thus, in all probability, been built up by coral-reef organisms upon the submerged lowlands of Viti Levu.

Vanua Levu.—The topography of this great island (2,700 square miles) is very similar to that of Viti Levu, and the main points in the history of its Barrier Reef may be explained in a similar manner.

Vanua Mbalavu.—This is one island, among several, lying within a large lagoon encircled by a barrier reef. The name signifies 'The Long Land.' The island itself has the shape of a distorted S, and consists of volcanic rock in the central portion dissected by ordinary stream action, and covered with deep deposits of *tala-singa*, or red earth, and terminated both north and south by masses of dense 'coral-reef' limestone, reaching a height of 500 feet. The volcanic rock of the central portion of Vanua Mbalavu also rises to similar heights. The raised 'reef-limestones' occurring north and south of the island overlie large masses of hard, granular, well-bedded, and evenly-dipping limestone. Well-bedded layers of fine volcanic ash (Fiji soapstone), with even dip, also occur at Vanua Mbalavu, but such beds were observed only as denuded islets near the island itself, and their relations to the 'coral-reef' limestone were not ascertained. In Mango, however, an island distant only a few miles from Vanua Mbalavu, soapstone beds of similar nature were observed dipping at an angle of 15 degrees, and capped by horizontal masses of reef limestone. The 'reef' limestones in the north of Vanua Mbalavu form islets separated by deep-water lanes, which pass, in one portion of Vanua Mbalavu at least, into a deep harbor running up among bedded limestones on the one side and volcanic rocks on the other. This harbor also belongs to the type universally admitted as drowned stream valleys, the valley having been formed by stream erosion in the first place while its profiles may be seen to have been partly submerged in recent geological time.

The association of these features suggests a basement of limestone and volcanic ash, originally deposited as beds of gentle, or negligible, dip. These appear to have been tilted



through an angle of from 10 to 20 degrees to the horizontal. The relation between the ash beds, the limestones and the volcanic rocks was not ascertained, although, judged by analogy with other similar exposures in Fiji, the volcanic rocks formed a base, while the bedded limestones and soapstones belong to one period of deposition. The younger terraced limestones were formed later, and elevated again at a later period, with pauses. The great dissection of these limestones was the work of streams.

This interpretation may be considered as open to question. Thus it may be considered that the limestone and volcanic-ash beds forming the basement of the raised 'reef-limestones' represent merely one stage in the formation of the reefs, namely, an outwash of the eroded basal volcanic rock and a simultaneous deposition elsewhere of calcareous organisms in the layers, while the 'reef-limestone' was being deposited in the clearer water offshore. In this connection, however, it may be pointed out, firstly, that the 'coral-reef limestones' overlie both the bedded limestones and volcanic ash, and, in the second place, the great thickness of the uniformly-dipping, and well-bedded, underlying limestone series suggests the formation of the same during a period of submergence prior to the formation of the superposed, and horizontal, 'coral-reef limestones'. In Viti Lévu also beds of Fiji soapstone (volcanic ash) and coral-reef limestone alternate with each other.

Vátu Vará, or Hat Island, is a mass of raised 'reef-limestone', 1,030 feet in height. No sign of rock other than limestone was observed. The lower 100 feet represent the brim, while the upper portion is almost perpendicular, and suggests the crown of a hat. Three horizontal lines of marine erosion occur within 50 feet above sea level.

Vátu Léile.—This is a small island which comprises a steep narrow portion composed entirely of a dense and hard 'reef-limestone' rising to a height of 110 feet above sea level, ending in a vertical cliff on one side and overlooking a wide and low limestone flat on the other, and a flat on which traces of volcanic rock are to be seen outcropping. On the vertical cliff face several distinct lines of marine erosion, disposed horizontally, may be seen, one above the other within a height of 50 feet above sea level. The higher lines have been almost obliterated through infilling by stalactitic growths of limestone, but the lowest line is still a well-marked feature. At one place, at least, it appears to form the landward limit of a raised 'coral-reef limestone' platform covered with corals of fresh appearance. A barrier reef encircles the island, which does not appear to rise above high water mark.

The simplest explanation of the origin of this island appears to be that a basement, either of volcanic rock, or limestone, or of both, was submerged, and a mass of coral with a precipitous western face was formed. The limestone thus formed subsequently was raised above sea level. The elevation occurred in stages interrupted by pauses during which the sea cut long horizontal lines in the cliff face, the original profiles of the cliff being preserved in the main during the intermittent uplift and marine erosion, although the tendency was to produce a cliff somewhat overhanging. During the formation of the line of erosion which occurs a few feet above sea level, a small fringing reef appears to have been formed, suggesting that a reef may be built up actually at sea level, while a raised reef, at the same time, may be undergoing demolition by wave action on the landward edge of this growing reef. The wide flat on the eastern portion of Vátu Léile may be due to growths of coral reef organisms during a pause in this uplift. The existence of the present Barrier Reef at sea level suggests a recent submergence of the island, inasmuch as, if this reef had been in existence during the various uplifts, suggested by a study of the cliff face, it should have been elevated with the main island.

Other islands might be described, such as *Fulánga*, or *Mángo*, *Naitámá*, *Yatháta*, *Thithia*, *Tuvuthá*, and *Thikombia*, in which it may be noted, as with the islands already described, that each has had an individual history especially in connection with the amounts of submergence and emergence involved. Thus the *Vátu Vará* limestone occurs 1,030 feet above sea level and exhibits traces of numerous movements of elevation in recent time, while the *Mángo* limestone, distant only a few miles, is only 550 feet in height and suggests submergence instead of emergence, during its later phases. The *Vátu Léile* 'reef-limestone' also is 110 feet high and shows numerous traces of recent emergence, while the raised 'reef-limestones' of the neighbouring coast of *Viti Lévu* are probably not more than 25 feet above sea level and the whole coast of this great island has been affected by pronounced stream action and submergence in recent time. The independent testimony, however, of the majority of the islands is that the present Barrier Reefs are due to the upward and outward growth of coral-reef organisms upon land areas recently submerged.

SCIENTIFIC INTELLIGENCE.

I. CHEMISTRY AND PHYSICS.

1. *The Separation of Yttrium from the Yttrium Earths.*—Professor James and his co-workers have tried many reagents in order to discover the most suitable ones for the separation of certain rare earths from each other. In a recent article J. B. BONARDI and C. JAMES have described a continued search for a rapid, efficient and economical method for the separation of yttrium from the accompanying yttrium earths. The process used in each case was the fractional precipitation of the mixture by means of successive additions of the reagent. The extent of the separation was then ascertained, usually by making atomic weight determinations upon the earths obtained in the succeeding fractions, but in some instances the unchanged color of the earths gave sufficient indication of unsatisfactory separation. The reagents tried were ammonium sebacate, azobenzene sulphonic acid, potassium sulphite, sodium citrate, sodium tungstate, sodium tartrate, sodium *m*-nitrobenzoate, ammonium camphorate, sodium phenoxacetate, and potassium cobalticyanide. The last reagent mentioned gave the most promising results. The neutral solution of the chlorides was heated to boiling and stirred while a solution of potassium cobalticyanide was slowly added. The precipitates were white and granular and filtered easily. Five fractions obtained from a mixture of earths in this way gave the following results:

	1	2	3	4	5
Atomic weight	98.7	95.1	90.8	88.2	90.5
Weight of fraction	11.9 g.	11.3 g.	10.4 g.	4.1 g.	0.7 g.

Fraction 5, which was precipitated with oxalic acid after four previous precipitations with the cobalticyanide, showed an unexpectedly high atomic weight, but it was found to be contaminated with neodymium, a rare earth metal of high atomic weight, belonging to another group. This fraction and fraction 4 showed an entire absence of the erbium bands in the absorption spectrum. The oxides of these two fractions were white, while fraction 1 gave oxides of a decidedly pink tint. The authors consider this method for the preparation of pure yttrium one of the most rapid that they know, and they propose to carry on further investigations soon with this very interesting reagent.—*Jour. Amer. Chem. Soc.*, xxxvii, 2642.

H. L. W.

2. *A Volumetric Method for Potassium.*—G. AJON has proposed the following method for application to fertilizers, and states that it yields accurate results. Put into an Erlenmeyer flask 25^{cc} of a 2 per cent KCl or K₂SO₄ solution, add slowly while agitating 50^{cc} of 2 *N* tartaric acid and then 25^{cc} of 0.5 *N* NaOH solution. Shake for 5 min. with a rotary motion, then

add little by little while still shaking 25°C of 96 per cent alcohol and let stand 6–8 hours. Decant the liquid through a 9^{cm} “barium sulphate” filter, wash the precipitate six times by decantation with neutral 96 per cent alcohol, remove the filter from the funnel and place it in the flask containing the precipitate. Then, using phenolphthalein, titrate with 0.1 *N* NaOH in alcohol to alkaline reaction. The end red color should persist for 5 min. Then dissolve the precipitate in 0.1 *N* aqueous NaOH and titrate the excess with 0.1 *N* HCl. The NaOH used to dissolve the bitartrate represents the K_2O present, the factor being 0.00471. The principle of the method is interesting but nothing is said as to the reason for making alkaline with alcoholic sodium hydroxide before the actual titration, nor is any statement made in regard to the interference of salts of magnesium or other metals with the process.—*Chem. Abstracts*, ix, 3188.

H. L. W.

3. *Potash from Feldspar*.—In view of the present scarcity of potash in the United States a writer in “Chemical Engineer” has discussed this possible source of the material. It is stated that the cost in Germany of producing one “unit” of potash (20 lbs. of K_2O) in the form of commercial “muriate” is less than 15 cents, and that it could be delivered in the United States at a profit at the rate of 30 cents per unit. Therefore any process must yield potash at a lower price than the one last mentioned in order to survive future German competition. Feldspar deposits of vast extent have been located having an average run-of-mine composition as follows:

Potassium oxide, K_2O	11 per cent.
Sodium oxide, Na_2O	2 “
Silica, SiO_2	70 “
Alumina, Al_2O_3	17 “

Many processes have been proposed for the extraction of the potash from feldspar, but they are generally very unpromising as far as competition with the German supply is concerned. Some of the prominent methods propose, after ignition with lime, to use the residue for making Portland cement, but since the clay and lime used for this industry usually cost less than 3 cents per 100 lbs., the values are discouragingly low. Such processes as propose to separate and save the alumina are confronted by competition with natural bauxite. One of these proposed processes is theoretically interesting. It consists in heating the feldspar with potassium chloride to 1050°C . when aluminium chloride sublimes off. The remaining potassium silicate is easily converted into potassium carbonate and an iron-free silica. The aluminium chloride may be converted into alumina and carbon oxychloride. The latter, it is said, acts upon hot feldspar to produce potassium chloride.

The article under review finally discusses an operation starting with phosphate rock, common salt, feldspar and carbon dioxide from the combustion of coal, and producing phosphoric acid, soda ash, potassium chloride and alumina. It appears, however,

that some of the reactions expected to take place in this process are absolutely impossible.—*Chem. News*, cxii, 265. H. L. W.

4. *An Introduction to Chemical Analyses*, by ELBERT W. ROCKWOOD. 8vo, pp. 247. Philadelphia, 1913 (P. Blakiston's Son & Co.).—This is the fourth revised edition of a work which is intended for the use of students of medicine, pharmacy and dentistry. The first part deals extensively with qualitative analysis and gives, besides the usual metal and acid analysis, the reactions of a considerable number of important organic substances, including a few of the alkaloids. The second part takes up volumetric analysis, giving some of the more important methods, while the third part deals with applied analysis, including a fairly extensive course on sanitary water analysis, and brief courses on the detection of poisons and blowpipe analysis. The book appears to be well written and accurate in its statements, and it seems to be well adapted for the purpose in view. It would seem, however, that although the courses laid out give a certain amount of practice in weighing, the book would have been improved if a little gravimetric analysis had been included.

H. L. W.

5. *Laboratory Manual, Arranged to Accompany "A Course in Chemistry"*, by WILLIAM MCPHERSON and WILLIAM EDWARDS HENDERSON. 8vo, pp. 141. Boston, 1915 (Ginn and Company. Price 60c. net.).—This book is a suitable companion to the authors' well-known text book and it gives an excellent series of experiments for laboratory work in connection with the study of elementary chemistry. The experiments are very well chosen and they are clearly described. The course laid out is rather extensive, and it includes a good proportion of quantitative exercises, but the book may be used satisfactorily for shorter courses by making proper omissions.

H. L. W.

6. *Fluorescence and Resonance of Sodium Vapor*.—In addition to the facts summarized in the last number of this Journal, R. J. STRUTT has recorded in another article the details of the experiments which led to the following results:

(a) When sodium vapor is excited by the D lines the centers emitting resonance radiation lose their ability of sending out light of observable intensity at the instant when they leave the beam of stimulating radiation. Although this phenomenon had been previously obtained by Dunoyer, the experimental procedure of Strutt was not open to the objections which could be raised against the method followed by the earlier investigator. In commenting on this phenomenon the later writer lays stress on the facts that electrical excitation is persistent whereas fluorescent stimulation is not so. Strutt says: "This will appear still more remarkable and anomalous if we compare the behaviour of sodium emitting the D line with mercury emitting the ultra-violet line at $\lambda 2536$. Mercury through which the electric discharge is passing emits this line along with the rest of the arc spectrum, and continues to do so for a time when distilled away from the place of

excitation. As Wood has shown, mercury vapour can also emit the line $\lambda 2536$ without the other mercury lines when light of precisely this wave-length falls upon it. So far the behaviour of mercury and sodium run parallel. Now comes the difference. The luminous centres emitting mercury resonance radiation of wave-length 2356 can be distilled away from the place of excitation as well and easily as if they had been excited electrically. The centres emitting the resonance radiation of sodium cannot, as we have seen, be distilled away from the place of excitation at all. I cannot at present make any suggestion as to how these facts should be regarded. It seems very strange that the analogy between the behaviour of sodium and mercury should go so far, and then suddenly break down."

(b) A layer of very dilute sodium vapor, which is quite transparent to white light, does not allow the resonance radiation of sodium to pass through it. This accounts for the fact that the spot of superficial resonance produced next to the inner wall of the glass container, at the place where the exciting light enters the vapor, can only be seen from the front, that is, in such a direction as to enable the light to fall upon the retina without traversing sodium vapor. "From the back it cannot be seen, as Dunoyer has observed."

(c) The intensity of the resonance radiation of sodium vapor is dependent upon the strength of the magnetic field in which the vapor is placed. If the exciting flame contains only a small proportion of salt the resonance radiation diminishes as the field increases. If the exciting flame is rich in sodium the resonance radiation first rises to a maximum and then diminishes as the field increases.

(d) When the stimulating source is placed in the magnetic field a dilute flame gives diminished resonance radiation while a concentrated flame gives increased resonance radiation. In this connection Strutt says: "The experiment serves as a striking demonstration of the Zeeman effect, and of the various experiments described it is perhaps the best for this purpose. Since the vessel containing sodium vapour has not to get into the space between the magnet poles, it can be made large, and a large patch of resonance radiation produced upon it. The effect of the field on this could quite well be shown to 10 or 20 persons at once."

All of the phenomena involved in cases (c) and (d) can be satisfactorily accounted for by elementary considerations involving a knowledge of the number of Zeeman components of each D line, of the wave-length of each component in a given magnetic field, of the breadth of the lines, and of the self-reversals of the lines.—*Proc. Roy. Soc.*, vol. xci (A), p. 388, June, 1915. H. S. U.

7. *The β -Rays from Radium D.*—By making use of an α -ray electroscope and by taking special precautions LISE MEITNER has succeeded in demonstrating electroscopically the existence of the β -rays from RaD. In collaboration with von Baeyer

and Hahn she showed by the magnetic spectrum method, in the year 1911, that the velocities of these rays vary from 0.33 to 0.39 of the velocity of light. Thus it appears that these are the slowest β -rays that have as yet been successfully studied electroscopically. The absorption coefficients in aluminium were found to be about 5500 cm^{-1} . Therefore the value 130 cm^{-1} given by Kovarik and generally incorporated in the recent literature of the subject is now to be considered incorrect.

The author adduces evidence to show that the absorption (Steckenbleiben) of β -rays by matter cannot consist in the gradual nullification of the speed by numerous successive collisions with the molecules. The β -particles presumably penetrate into the interior of the absorbing atoms and are held fast there under certain conditions, that is, they lose their energy in one single collision.—*Phys. Zeitschr.*, August 1, 1915, p. 272. H. S. U.

8. *Introduction to Magnetism and Electricity*; by E. W. E. KEMPSON. Pp. viii, 240, with 158 figures. New York, 1915 (Longmans, Green and Co.).—The following sentences quoted from the author's preface give a concise idea of the origin and object of the text. "This book is made up from lecture notes for a year's course of Electricity and Magnetism as given to Science Forms in the Upper School at Rugby." "It should be understood that students using this book are expected to have at least one period of say one and a half or two hours per week of practical work in the laboratory, as well as a course of lectures and discussions on the subject."

In arranging and presenting the material a special effort has been made to emphasize the identity of electricity generated in different ways and, in particular, to use the study of static phenomena as a real help to the correct understanding of electricity in motion. The first three chapters (46 pages) are devoted to magnetism and the remaining sixteen to electricity. A proper appreciation of the experiments suggested is facilitated by clear diagrams of the apparatus to be employed and by graphical and numerical illustrations of the results obtained in practice. A summary of the most important facts presented is given at the end of each chapter. Also, with the exception of Chapters I and XV, a set of problems (147 in all) for solution by the student follows each summary. Numerical answers are given immediately before the index. So far as we can judge, without testing the text with classes of beginners, the book seems to be admirably designed to meet the requirements of its readers. H. S. U.

9. *An Introduction to the Mechanics of Fluids*; by EDWIN H. BARTON. Pp. xiv, 249, with 130 figures. London, 1915 (Longmans, Green and Co.).—In writing this book the author has endeavored to make it suitable for candidates for entrance scholarship and other university examinations, for naval and military preparation, and for those technical students taking the Board of Education's lower examination in Theoretical Mechanics (Fluids), or any of a similar character held by the various provincial edu-

cational unions. "As to mathematical scope, the calculus is not used, but, in avoiding it, a summational formula is given, and, so far as may be, established."

The text is divided into five Parts which deal respectively with the mechanical basis of the subject, hydrostatics, hydrokinetics, pneumatics, and practical applications. A large number of examples and problems (507) are distributed throughout the text and near the end of the volume. Not only are all the numerical answers given but a special section is devoted to solutions and to hints regarding the solutions of the more difficult problems. This is followed by the examination questions set by the Board of Education for the years 1912, 1913, and 1914. Tables of physical and mathematical constants precede the index.

The subject matter is presented in a clear, accurate, and up to date manner. For illustration, the laws of motion are first formulated according to Newton and then in the modern, almost unimpeachable phraseology of Mach. The student's interest in the subject is stimulated by numerous practical applications such as Giffard's injector, the pulsometer steam pump, Humphrey's internal-combustion pump, the intensifying accumulator, torpedo compressors, Gaede's molecular pump, the Blount door check, the Westinghouse air-brake, etc. The diagrams are large and clear, and the number of typographical errors is small. It is therefore clear that the book has made a very favorable impression on the mind of the writer of this brief notice.

H. S. U.

II. GEOLOGY AND NATURAL HISTORY.

1. *Triassic Life of the Connecticut Valley*; by RICHARD S. LULL. Bull. 24, Connecticut Geol. and Nat. Hist. Surv., 1915, pp. 285, 3 maps, 12 pls., 126 figs.—Even though the formations of Triassic age in the Connecticut valley yield but few actual organic remains, yet the abundance of trails and footprints in the muds and sands of this time has deeply interested geologists for nearly a century. Professor Lull in this valuable bulletin brings together all that is known of the fossils of this time in the Connecticut valley, with the view of presenting them as living things, surrounded by the environment of their time. The thickness of the rock series is at least 10,000 feet and may exceed 13,000 feet. Of plants there are 5 conifers, 4 cycads, 1 equisetum, and 2 or 3 ferns; of animal remains there are 1 insect larva, 2 fresh-water bivalves, 20 species of ganoid fishes in 6 genera, 2 aëtosaurus, 2 phytosaurs, and 5 dinosaurs; of invertebrate trails there are 49 forms in 27 genera; and of vertebrate footprints the astonishing number of 99 species in 44 genera.

Among the author's more important conclusions are the following:

"The older notions of the submarine or estuarine origin of these rocks have been abandoned on the ground of their contain-

ing no relics whatever of marine or even brackish-water origin. . . On the other hand, evidence seems to point to continental deposits, the result of the ordinary subaërial agencies of winds and rains and rivers" (39).

"The terrestrial vertebrate skeletons are all reptilian remains; three, those of phytosaurs, remotely related to living crocodiles, and, in one instance at least, æcologically equivalent to the fish-eating gavials of the Far East. The others are all dinosaurs of average size and representative kinds, neither the largest nor the most specialized which lived during the time of which we speak.

"The footprints doubtless represent two, possibly three, great classes of terrestrial beings: Amphibia of salamandrine form were perhaps present, and doubtless representatives of the more archaic armored stegocephalians as well, though one cannot indicate the tracks of either with assurance. Of the reptiles, the possibilities of time and place would indicate lizards, turtles, and dinosaurs among the more familiar forms, and these unquestionably were represented in the fauna; and among those less known the Rhynchocephalia, phytosaurs, aëtosaurus, and theromorphs are within the possibilities. Whether or not birds were present is a mooted question" (41-42).

C. S.

2. *Central Connecticut in the Geologic Past*; by JOSEPH BARRELL. Bull. 23, Connecticut Geol. and Nat. Hist. Surv., 1915, pp. 44, 5 pls.—The author describes and illustrates the physical history, i. e., the periods of elevation and peneplanation that the Connecticut valley has undergone since late Paleozoic time. Of particular interest are Barrell's eight very original "structure sections," diagrams that not only show the topography of the time depicted, but the inferred underground geology as well. The whole is presented in an interesting manner.

C. S.

3. *Bibliographic Index of American Ordovician and Silurian Fossils*; by RAY S. BASSLER. Bull. 92, U. S. National Museum, 1915, pp. 1521, 4 pls. (tables).—This great labor of love is a boon to all paleontologists working with Ordovician and Silurian fossils and stratigraphy. The work gives the entire bibliography and synonymy of the hundreds of genera and thousands of species found in North America in rocks of the two periods mentioned. In addition the genotypes of the genera are given, and also the formation, the type locality, and the known wider distribution of the species. In cases where the U. S. National Museum has type material, this is noted. At the end of the bibliography is given an index of specific names and their generic combinations (pages 1343-1406), a biological classification and index of genera (1407-1440), faunal lists of American Ozarkian to lowest Helderbergian forms (1441-1509), and a list of American Ordovician and Silurian formations (1511-1521). Finally at the end of the work are four very important correlation tables of the geologic divisions and their occurrence in the various basins of deposit. Doctor Bassler is to be congratulated upon the completion of his great and valuable undertaking.

The author thinks it wise to refer the Richmondian series to the Silurian (see plate 3 and pages 1476-1483), but nothing is said in his preface about this radical departure from the long accepted usage of regarding this series as the closing one of the Ordovician. C. S.

4. *Fifth Annual Report of the Director of the Bureau of Mines for the year ending June 30, 1915.* Pp. 106; 1 plate, 1 fig. Washington, 1915.—The death, last July, of Dr. Joseph A. Holmes, under whom, as director, the Bureau of Mines was organized and developed to a high degree of efficiency, was a great blow to all the interests involved. Fortunately it has been possible for one of his former associates, Mr. Van. H. Mannig, to take up his task and carry on the work. The progress made, up to July first, along the lines already laid down, is shown in the present Report; until near the end of his life, Dr. Holmes, although driven to Colorado by failing health, was able to exercise general supervision of the work going on.

The essential objects of the Bureau, as well understood, are to protect the safety and health of mine workers, and to promote greater efficiency and diminish the waste in the production of our mineral resources. These fundamental objects have so many applications of different kinds that a brief summary of the work of the past year includes the enumeration of upward of fifty investigations. It is found, however, that the demands upon the Bureau grow more rapidly than the ability to meet them, so that increased funds and equipments are urgently called for. The total sum disbursed for the year under consideration was only \$730,000, a small amount in consideration of what was accomplished. The publications of the year include 12 bulletins, 18 technical papers and 4 minor circulars, and more than 950,000 copies of these were distributed.

The following are the titles of Bulletins recently issued (see vol. xl, p. 87):

No. 72. Occurrence of explosive gases in coal mines; by N. H. DARTON. Pp. 248; 7 pls., 33 figs.

No. 75. Rules and regulations for metal mines; by W. R. INGALLS, JAMES DOUGLAS and others. Pp. xvi, 296; 39 tables.

No. 94. United States mining statutes annotated; by J. W. THOMPSON. Part I. Sections and statutes relating to metalliferous and coal mining. Pp. xxxix, 860. Part II. Miscellaneous mining subjects. Pp. xxxv, 861-1772.

No. 98. Report of the Selby Smelter Commission; by J. A. HOLMES, EDWARD C. FRANKLIN and RALPH A. GOULD. With accompanying papers. Pp. xv, 528; 41 pls., 14 figs.

No. 101. Abstracts of current decisions on mines and mining, October, 1914, to April, 1915; by J. W. THOMPSON. Pp. xiv, 136.

5. *Determinative Mineralogy*; by J. VOLNEY LEWIS. Second revised Edition. Pp. 155. New York, 1915 (John Wiley and Sons).—This book, the original edition of which appeared in 1912,

is chiefly made up of a series of determinative mineral tables based on chemical and blowpipe tests. That it has met with a deserved success is shown by the printing of a new and revised edition after such a short time. The new edition, while in large measure the same as the first edition, has had certain changes incorporated into it that serve to make the tables clearer and more complete. It is still to be regretted that the excessive abbreviation of the description of reactions, etc., has been retained. The gain in space obtained by this method would seem to be more than offset by the constant difficulties in reading that it causes.

W. E. F.

6. *A Monograph of the Existing Crinoids*; by AUSTIN HOBART CLARK. Vol. I, *The Comatulids*. Part I. Pp. vi, 406, with 17 plates and 513 figures in the text. Bull. 82, U. S. National Museum. Washington, 1915 (Government Printing Office).—The general conception that the crinoids represent a fast declining remnant of a once flourishing stock must be somewhat modified by this elaborate monograph, which contains the results of the study not only of the author's extensive personal collections but also of representatives from all the large museums of the world. The author states that during the cruise of the *Albatross* in the North Pacific: "I handled tens of thousands of specimens; several times I saw the forward deck of the steamer literally buried under several tons of individuals belonging to a species exceeding any fossil form in size; everywhere we went we found crinoids; we dredged them at all depths; . . . surely a group so abundant . . . cannot be considered as decadent or degenerate."

This first volume is introductory to the systematic treatise which is to follow. After an extensive historical review, the author discusses and revises our knowledge of the structure and relationships of the crinoids and the anatomy and natural history of each of the existing groups. Each of the types of structure is very fully described and illustrated both by outline drawings and photographs.

W. R. C.

7. *Practical Zoology*; by ROBERT W. HEGNER. Pp. xv, 495, with 326 figures. New York, 1915 (The Macmillan Co.).—Those animals which in some way affect the human welfare have been chosen to illustrate the general principles of the science in this elementary textbook, designed for use in secondary schools. In its general plan the book follows a systematic survey of the animal kingdom, but with particular emphasis on those groups which are of practical importance. There are chapters on the protection of useful birds, mammals and other beneficial animals, and suggestions for the destruction of those that are directly or indirectly injurious. The author's aim to interest as well as instruct the pupil in the subject is likely to be fully realized, for the most interesting facts about the various groups of animals have been given in a pleasing style, accompanied by illustrations which are largely original and of real human interest.

W. R. C.

8. *A Course in Invertebrate Zoology*; by HENRY SHERRING PRATT. Revised edition. Pp. xii, 228. Boston, 1915 (Ginn and

Co.).—This widely used laboratory manual contains well arranged directions for the study and dissection of representatives of each of the principal groups of invertebrate animals. The new edition contains a number of additional dissections and a revised scheme of classification. Complete directions are thus made available for the laboratory study of forty different species. A wide range in the selection of forms for study in zoological courses is thereby made possible.

W. R. C.

9. *The Meaning of Evolution*; by SAMUEL CHRISTIAN SCHMUCKER. Pp. 305. New York, 1915 (The Macmillan Company).—The writer sketches in a popular style the development of the doctrine of evolution from the earliest times to the present. He briefly reviews the life and influence of Darwin and Wallace, and then states and examines the evidence in support of their theory. He includes many interesting personal observations. The evolutionary theories since Darwin, the future evolution of man, and the relation of biological science to religious beliefs are also discussed. The book will appeal to the general reader rather than to the trained biologist.

W. R. C.

10. *Lessons in Elementary Physiology*; by THOMAS H. HUXLEY. Sixth edition, enlarged and revised. Pp. xxiv, 604, with 185 figures. New York, 1915 (The Macmillan Company).—For almost exactly a half century this textbook has stood as a model of clear, concise, expository writing. Few scientists of any time have equalled this great master in ability to present the essentials of a science in a manner both comprehensive and elementary. Huxley's original book was thoroughly revised by Foster many years ago, and has now been brought up to date by Joseph Barcroft. The present edition fortunately retains the full force of Huxley's power of expression, with such revisions and additions as are necessary to make the work as useful to the present generation as the older editions have been to the past.

W. R. C.

11. *Diversions of a Naturalist*; by SIR RAY LANKESTER. Pp. xvi, 424, with 44 illustrations. New York, 1915 (The Macmillan Company).—The book consists of some forty brief essays of a popular nature, originally printed as newspaper articles. They embrace a great range of topics in many branches of science, although most of them have some bearing on animal life. Written in an easy, conversational style, with many interesting anecdotes and charming reminiscences, these essays furnish entertaining reading for anyone at all interested in biology or general science. Aside from the pleasure of its reading, however, the book has a real educational value, for each topic is based on scientific truths of general interest.

W. R. C.

12. *Beekeeping*; by E. F. PHILLIPS. Pp. xxii, 457, with 190 figures. The Rural Science Series. New York, 1915 (The Macmillan Co.).—The author's long experience in charge of the office of bee culture investigations of the United States Bureau of Entomology has enabled him to anticipate the needs of the

practical beekeeper, for whom this book is especially designed. There are complete directions for the management of bees and the marketing of their products, together with a thoroughly scientific account of the bee's anatomy, life history, habits, and diseases. The book will serve a much wider sphere of usefulness, however, than merely filling the needs of the bee culturist, for it contains such a wealth of reliable information concerning these wonderful insects that it is likely to become a classic for the biologist and entomologist as well.

W. R. C.

OBITUARY.

DR. ARTHUR WILLIAMS WRIGHT, professor of experimental physics in Yale University from 1887-1906, died at his home in New Haven on December 19 in the eightieth year of his age. A notice is deferred till a later number.

DR. ORVILLE ADELBERT DERBY, the geologist, died suddenly at Rio Janeiro on November 27 at the age of sixty-four years. He was instructor in geology at Cornell University from 1873 to 1875, when he went to Brazil to become connected with the Geological Survey. To this work he devoted his life, being made later the head of the Survey. His investigations were of great value both in geology and mineralogy; many of them were published in the pages of this Journal.

DR. CHARLES FREDERICK HOLDER, the naturalist, at one time assistant curator in the American Museum of Natural History, died at his home in Pasadena on October 10 at the age of sixty-four years.

SIR HENRY ENFIELD ROSCOE, the veteran English chemist, died on December 19 in the eighty-third year of his age; few men have attained an equal eminence in science and in public life.

DR. H. CHARLTON BASTIAN died on November 17 at the age of seventy-eight years. He was an authority on nervous affections and had made a special study of the nervous system of the brain. The investigations and speculations for which he will be specially remembered deal with origin of life, as he believed from non-living elements, and with the doctrine of "heterogenesis."

DR. C. J. BOUCHARD, professor of pathology in the University of Paris, died in November at the advanced age of seventy-eight years.

DR. R. ASSHETON, the English zoologist, died on October 24, at the age of fifty-two years.

SIR ARTHUR RÜCKER, principal of the University of London from 1901 to 1908, and earlier professor of physics at the Royal School of Science, South Kensington, died on November 1 at the age of sixty-seven years.

DR. GASTON VASSEUR, professor of geology in the University of Marseilles, died early in November at the age of sixty years.

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NOTE.—The extra expense involved in the publication of the article on the Cuzco Valley by H. E. Gregory (pp. 1-100), particularly as to illustrations and maps, has been assumed by the National Geographic Society of Washington.—ED.

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WITH PLATE III

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The lava lake, Halemau-man, at Kilauea, from the southeast. Photograph by H. E. Wilson, August 26th, 1910.

THE

AMERICAN JOURNAL OF SCIENCE

[FOURTH SERIES.]

ART. VII.—*Problems of the Pacific Islands*;* by REGINALD A. DALY, Harvard University. With Plate III.

CONTENTS.

- Proposal for future research.
 - Preliminary statement.
 - Need of comprehensive exploration.
 - Field considered.
 - Duration and cost of the work.
 - The problems.
- Islands showing outcrops of continental rocks.
- Volcanic islands.
 - Petrography.
 - Origin of the lavas.
 - Nature of volcanic action.
- Origin of limestone.
- Coral islands.
 - Subsidence theory of coral reefs.
 - Glacial-control theory of coral reefs.
- Review and conclusion.

Proposal for Future Research.

Preliminary statement.—The Greeks thought the Pillars of Hercules to be the western end of the world. It has been the glory of civilization to prove they were wrong. Unconsciously, but all the more courageously, the Atlantic was spanned and its conscious exploration, though still incomplete, has taken the effort of four centuries and many nations. The wave of adventure and manly curiosity early swept across the New World, but only now is knowledge of the extent and value of its continents for our race become fixed in grand outline. As we look from the hills of Berkeley, still westward, through

* An address given at a general meeting of the American Association for the Advancement of Science, at San Francisco, August third, nineteen hundred and fifteen.

another world gateway, one-third of the earth's circumference from Gibraltar, the last great field for scientific conquest sparkles in our eyes.

Beyond the Pacific is the Old World, rapidly yielding its last secrets to its own peoples. Is not the piercing of Panama a suggestion, a brilliant symbol, for American geographical science? The Golden Gate is not the end of the world for it. Already Dana has made immortal the Wilkes expedition to the South Sea; Brigham at Honolulu has long been a clearing-house for ideas regarding the culture of Polynesia; Agassiz has lavished his vast energies in reconnaissance of the Pacific islands; Californians have brought rich scientific booty from the Channel islands and from Galapagos; the founding of a volcanological observatory in Hawaii is an important step in the American exploration; two Harvard expeditions to the southwestern Pacific within the last eighteen months deal with island problems full of meaning for general science. To the many researches of individuals are to be added those of government bureaus—Hydrographic Office, Coast and Geodetic Survey, Geological Survey, and Fish Commission—operating chiefly on mainland and island coasts which are under the American flag.

To the government bureaus, or scientific bodies of the different nations concerned, may be assigned the duty of scientific exploration in the Aleutian, Kurile, Japanese, and East Indian archipelagoes; but Polynesia, Micronesia, and Melanesia need different treatment. My thesis to-night is that the thorough study of these oceanic islands offers a highly desirable program for large-scale private enterprise in science, and that the program is highly appropriate for American enterprise in particular. The citizens of this republic co-operated to build the marvellous canal, opening a new, main door to the Pacific. Their engineers did it under the control of the general government. The systematic exploration of archipelagoes which are under a half-dozen flags obviously cannot be undertaken by any government, but, with private association, the citizens of America are perfectly capable of attacking the task in pure science, which is at once less than, and greater than, the cutting of the Panama canal. Among the many projects submitted to this society for the advancement of science, no other seems more fitting on the present occasion; no other would seem more certain to yield new and important results.

Need of comprehensive exploration.—The history of natural science amply shows the waste of effort and the danger of positive error that are due to the compartment method of study. Much of the literature dealing with the principles of chemistry, published even in the last quarter of the nine-

teenth century, is now so much waste paper. Many chemists had failed to realize that chemical reaction is in large part a matter of pure physics. The essential truths of chemistry are now rapidly emerging as physical chemistry continues its epoch-making discoveries in the twentieth century. Another wall of partition has recently broken down as geologists in their turn have come to recognize that a quantitative understanding of energy is an absolute necessity for geology. Thus the borderland science, geophysics, is getting nearer the truth and sending to the scrap-heap whole libraries of works on the history of earth processes. But nowhere is the compartment system of studying nature more clearly at fault than in its application to questions of distribution. No zoologist can safely, truly describe the mechanism of animal distribution in a region without an understanding of animal distribution in surrounding areas, without an understanding of plant distribution, and without an understanding of geological conditions. Neither zoologist or botanist, dealing with the distribution of species, can afford to neglect the data of anthropogeography, meteorology, and oceanography. The welter of conflicting opinions as to the mapping of organic provinces, as to the possibilities of migration, as to the former existence of land bridges in areas now oceanic, is due in no small measure to the individualism of observers.

Of course, analysis must precede synthesis and specialization is increasingly more necessary for the field worker. Hence the only economical way of reaching the truth of nature is to co-operate, first, last, and all the time. A body of specialists, *together* questioning *all* of the Pacific oceanic islands, are sure to reach final results quicker than is possible to a much greater number of equally capable men who independently "monograph" island or island group. Regarding the origin and distribution of organisms or rocks, the testimony of a single island or group is bound to be doubtful. The very refinement of analysis in a restricted area may give misleading results and represent energy worse than wasted. A problem vital to the biology or geology of a single island or group may be supremely difficult, or impossible, of solution, if attacked merely in the light of local facts; yet the solution may soon be clear as day when information comes from neighboring islands or archipelagoes. Negatively, in the prevention of waste in energy, as well as positively, in the conscious adoption of the only feasible method of reaching final truths, the plan of comprehensive, synthetic exploration of the Pacific islands has claims for serious consideration.

The project implies that the specialist observers should be in the field a long time. For many problems, already insistent,

this is a very great advantage, not shared by the ordinary "monographic" method of work, which is now possible to the individual, however he be supported. Examples will occur to every naturalist. Mutational and experimental studies of endless variety need to run several years before valuable results are attainable. The same is largely true of the dynamics of organic distribution. The essence of volcanic action can only be determined by nearly continuous observation of vents for many years; already the Pacific volcanoes have probably taught us more concerning this fundamental subject than have all the other vents of the globe together. Determinations of the rates of change, such as that of coral or nullipore growth, are urgently needed, and a decade must give estimates much safer than those possible under the usual conditions of field work. For various reasons it is important to compare the erosive power of waves breaking on oceanic islands with the power of those which break on continental shores after running over the broad continental shelves; observations through a series of years can alone give the data. Continued, direct measurements on the Falcon shoal of the Tonga group—a recently formed mass of volcanic ash—can doubtless do much toward settling the important question as to the depth to which waves and currents can erode the ocean bottom.

Many other instances might be cited, but no naturalist needs to be further reminded of the value of ample *time* for his field studies, nor of the loss to science involved in the normal obligation to leave the field at the end of one or two seasons. Not less important than the allowance of time for the completion of dynamic studies, is the advantage of a plan whereby the observer himself becomes saturated with his large problem and fully matured in the power to solve it.

The project is further justified on account of the rapid destruction of aboriginal conditions in the Pacific islands by immigrant man. Already their primitive peoples have been largely displaced, degraded, or destroyed by the whites. With the savages and their customs and equipment have disappeared some precious data regarding the development of our race. The white man's interference with the native animals and plants is similarly and speedily increasing the difficulty of writing the natural history of the archipelagoes. Immediate scientific attack means simultaneous attack on the islands.

Again, the plan has a special advantage owing to its very bigness. To be workable at all, the scientific collections and laboratories should be concentrated as far as possible under one roof, though, of course, duplicate material might well be distributed among other museums of the United States. Such a central building should serve as the off-season home of the

scientific staff; a place where ideas are pooled and many comparative studies made; a hospitable roof under which would be gathered certain specialists, invited to work up the collections in their respective fields. Doubtless in some instances collections would be sent to other centers for study, but on their return to headquarters, these materials would become part of a main body forming a unique, permanent museum. Systematic arrangement of all collections at one locality must be of enormous value to the investigators. In contrast, think of the practical impossibility of thorough comparative studies among the existing Pacific collections, now housed in public and private establishments all over the earth!

One other of the main reasons for this comprehensive survey may be noted. The area concerned covers 35,000,000 square miles, but less than one per cent of it is land. Hence, so far as the islands themselves are concerned, their study, complete enough for the more pressing needs of science, is quite feasible. When accomplished, the work would have brought to book most of the essential facts which are ever likely to be won in the geology, anthropology, and biology of one-sixth of the earth's surface. It is safe to say that no other geographic province of equal land area will furnish such a rich store of facts. The correlation of these must fundamentally affect our understanding of the whole globe. Whatever else the outcome, the world of science would look with satisfaction at the record of what *can* be discovered and deduced regarding the land and shallow-water problems of the mid-Pacific.

Field considered.—What is the field under consideration? Most of the oceanic islands of the Pacific are included in the three major groups, Micronesia, Polynesia, and Melanesia. These are practically included between the parallels of 25° North Latitude and 25° South Latitude, and between the meridians of 130° East Longitude and 130° West Longitude. Thirty principal archipelagoes are there represented. A few other groups, including Juan Fernandez and Galapagos, as well as a number of small, isolated islands, lie outside the limits of Oceania proper. In Brigham's "Index" the names of 2600 islands and islets appear.* The names of about 600 islands are entered on his key maps. Apart from mere rocks or insignificant islets, the total number is probably about 3000.

Wagner, Supan, and a few other authorities have computed the areas of the different archipelagoes.† The results have been compiled in the form of the following table:

* W. T. Brigham, *Index to the Islands of the Pacific*, Memoirs Bishop Museum, Honolulu, vol. i, No. 2, 1900.

† H. Wagner and A. Supan, *Petermann's Geogr. Mitteilungen*, Erg. Hefte, vol. xxii, p. 236, 1891.

Areas of Pacific Islands.

<i>Group</i>	<i>Square kilometers</i>	<i>Square (statute) miles</i>
Pelew	503	194
Bonin and neighboring islands	110	42
Mariana	1,140	440
Caroline	1,450	560
Marshall	410	159
Hawaiian	17,008	6,566
Fanning (group)	668	258
D'Entrecasteaux	3,145	1,214
Louisiade	2,200	850
New Caledonia	16,920	6,528
Loyalty	2,743	1,059
Kermadec	33	13
Bismarck (including Admiralty Ids.)	47,100	18,184
Solomon	43,900	16,952
Santa Cruz	938	362
New Hebrides	13,227	5,107
Fiji	20,837	8,045
Tonga	997	385
Gilbert	430	166
Ellice	37	14
Samoa	2,787	1,076
Cook (Hervey)	368	142
Austral (Tubuai)	286	111
Tokelau (Union)	14	5
Phoenix	42	16
Manihiki	137	53
Society	1,650	637
Paumotu (Tuamotu)	978	378
Marquesas	1,274	492
Easter and Sala y Gomez Ids.	122	47
Cocos	33	13
Galapagos	7,643	2,952
Juan Fernandez (group)	187	72
	<hr/> 189,317	<hr/> 73,092

Adding the isolated islands, the total area is about 75,000 square miles. Of this, nearly one-half covers a dozen of the largest islands, including: Hawaii; Viti Levu and Vanua Levu of the Fiji group; New Pomerania and New Mecklenburg of the Bismarck group; and New Caledonia. These more important islands are likely to be studied carefully by their respective owners. The project now advocated has special reference to the thousands of smaller islands. Their total area is less than 50,000 square miles and is thus seen to imply a task not too great for private American enterprise.

Duration and cost of the work.—It needs no emphasis that the requisite financial and technical support for the scheme, as well as the time for its accomplishment, would depend on the mode of attack. "Strategic" islands, one or two to each archipelago, should be examined with great thoroughness. Their neighbors might be covered according to methods ranging from those of simple reconnaissance to those of more complete conquest. Thereby the plan is made not only workable but also elastic. According to the intensiveness of studies outside the "strategic" islands, the project has been roughly estimated to cost from \$800,000 to \$3,000,000. The field work should extend over a period of at least ten years, in order to allow for the necessary time factor in many observations. From five to ten years additional should be assumed for systematizing and publishing the results. An annual appropriation of \$100,000 during the period of continuous field work and an annual appropriation of \$50,000 to \$75,000 in the following years would assuredly guarantee success.

The problems.—The sanction for a scheme so ambitious is to be found ultimately in the dignity of the outstanding problems and of the many others which would inevitably crop out as the work progressed. For the remainder of my hour I wish to indicate the quality of some of those now in sight.

In the first place, there is urgent need of systematic achievement in the field of purely descriptive geography. A thoroughly satisfactory map of the Pacific, the delimitation of its archipelagoes, and a complete gazetteer showing the locations, areas, and heights of the islands, have yet to be made. Fuller discussion of the island synonymy may well supplement Brigham's monumental "Index to the islands of the Pacific." A map showing the submerged banks of this ocean would be a welcome aid to knowledge, for it would hasten our understanding of the islands themselves. Just this ideal led to the organization of the Stackhouse expedition. Now that its commander has been lost with the "Lusitania," his plan of studying the shallows in the Great Ocean may be long postponed; yet a compilation of data already in the hands of the world's admiralities would be very useful.

Physiographic students must long feel the lack of accurate contour maps. The extraordinarily fine map of Kauai, recently issued by the United States Geological Survey, is an example of the kind of cartography which the governments owning or "protecting" the islands may well imitate. In most cases the field worker in the islands must be content with hydrographic charts, more or less completely hachured, but the physiographer has here the special advantage of a sea-level datum generally in sight and is therefore more independent of perfect maps

than his colleague observing in continental interiors. The topographic development of oceanic islands is in general so peculiar that the trained physiographer will be amply repaid for any labor he may expend on them.

The physiography of the sea itself offers important questions which are best answered by observers along the island shores. The depths of the great ocean currents, their variations from the surface downward, their power to transport bottom sediment at different depths, their relation to the submarine shelves which encircle most islands, the water movements in the numerous island lagoons, the temperatures, salinity, and detailed chemistry of the subsurface waters within reefs and outside them—are all topics on which much information is needed. The same is true of the erosive efficiency of open-ocean waves, determining which almost nothing quantitative has yet been determined by observers on oceanic islands.

However, for general science the origin of the islands and the origin of their living inhabitants have the deepest significance. The geology and biology of the islands are important to a degree certainly not to be measured by the total land area involved. When the vast labor of determining all their faunas and floras is once brought to completion, the biology of the globe as a unit will be profoundly affected. A host of questions regarding the physiology, adaptations, dispersals, mutual relations, phylogeny and ontogeny of the plants and animals (including man) press for answer. Many of the answers must sway opinion as to biological essentials the world over.

Of these matters I am not competent to speak with authority. Yet it may tend to make the advisability of immediate exploration in the Pacific basin more vivid if I try to present concrete geological problems in some detail. With your indulgence, therefore, the origin of the islands themselves will be briefly discussed, with the definite purpose of illustrating the need for future investigation on the large scale.

The Pacific islands, which are not close to the continents, may be divided into five groups, according to the character of their rocks. A small number are composed of rock types characteristic of large areas in the continents, like granite, gneiss, schist, serpentine, and deformed sediments. Some of the high islands show none but volcanic constituents. Most of the low islands, in their visible parts, are composed wholly of limestone. Many of those betraying an essentially volcanic origin have limestones interbedded with, or resting on, the lava formations. Other composite islands, few in number, include continental rocks, volcanic rocks, and limestones of recent dates of formation. Each of the five groups has its own problems, but the fundamental questions now to be considered

fall under three heads: first, the distribution and origin of the islands containing rocks of the continental type: secondly, the nature of volcanic action in general: and lastly, the origin of the limestone formations, including coral reefs. Each of these topics has long been the object of research, but for none of them is there uniformity in expert opinion.

Islands Showing Outcrops of Continental Rocks.

The vast Eastern Archipelago, extending from Sumatra and the Philippines to New Guinea, has been formed by complicated movements of the earth's crust. In large part the included seas—the Banda, Java, Celebes, Mindoro, and China seas—seem to be due to the local submergence of crustal blocks which were once parts of a continental area. The satellitic islands close to New Guinea have been separated from that large island by subsidence. Evidence of such founderings are found in the detailed structures of the islands, as well as in the mineralogical content or petrography of the rocks. Crystalline schists, granitic masses, and old, deformed sediments—staple rocks of continental mountain ranges—constitute the great bulk of the Eastern Archipelago. How far do similar formations characterize Oceania proper? This is an old question, still without a satisfactory answer. Archipelagoes one thousand miles offshore from New Guinea or Australia are known to contain continental types of rock. In Oceania, outside of the Eastern Archipelago just described, continental types of rock appear in about thirty different islands. Most of these islands are located in the following groups: Bismarck, Bonin, Caroline, Chatham, Fiji, Kermadec, New Caledonia, Pelew, and Solomon. Deformed Miocene limestone is reported from Espiritu Santo island of the New Hebrides, and gneiss(?) from Malekula of the same group. Ellis described the occurrence of “quartz-feldspar rock” in Borabora of the Society group, but the report needs confirmation. Quartzose rocks are described from Norfolk, Bounty, Campbell, and The Snares—all isolated islands. Commander Thomson stated that he found granite and slate in Easter island.

Every one of these composite islands needs thorough study by able geologists, who are also trained in petrography. The Carolines, the Santa Cruz group, and the Tonga group are specially critical and deserve immediate attention. The reports of granitic rocks in Borabora and in Easter island should be checked by field work. Systematic investigation ought to replace the haphazard mode of discovery that has commonly ruled in regions of assumed continental fragmentation. The

extent of that fragmentation, its geological date or dates, its relation to the question of land bridges and the distribution of organisms, and its relation to volcanism in the Pacific are all matters of primary importance.

Connected therewith is the problem lately suggested by Molengraaff's and Brouwer's remarkable discoveries of typical radiolarian sediments, charged with manganese nodules, in the mountains of Borneo, Timor, and Roti.* This kind of sediment seems to be formed only in sea water more than 10,000 feet deep; yet Molengraaff has found it in mountains at 4000 feet above sea, and covering thousands of square miles in Borneo alone. Are there similar evidences of tremendous upheaval in Oceania? How far are the heights and hollows of the western Pacific due to warping of the earth's crust? How far to block-faulting?

One of the grandest, as well as clearest, proofs of recent crustal warping is due to Professor Lawson's pioneer studies of San Clemente and Santa Catalina, two Pacific islands of continental affinities. San Clemente has been recently uplifted about 1400 feet and, as shown in the Coast Survey chart, has a series of strand-lines engraved on it by the waves. Santa Catalina, a neighbor to San Clemente, has contemporaneously sunk. It lacks elevated sea-cliffs and, on the other hand, its shore-line has the appearance of having been drowned by subsidence. Professor Lawson's studies, like the later ones by Dr. W. S. Tangier Smith, have assuredly whetted the appetite of geologists for more information about the other islands of the Californian coast.

Volcanic Islands.

Let us now glance at the volcanic archipelagoes. Excluding New Guinea and its satellites, but including the Hawaiian, Galapagos, and Juan Fernandez groups, Oceania has 345 islands which are definitely described in the scientific literature as wholly or largely volcanic in origin. Probably the whole number showing volcanic rock above sea-level is at least twice as great. How many other volcanic masses exist as "banks" or as basements completely veneered by coral limestone is obviously unknown, but their number doubtless runs into the hundreds.

Petrography.—Among the ascertained volcanic islands, only 152 have yet afforded any petrographic data; of those not a half dozen have been examined with the thoroughness demanded by modern geologists. In order to summarize the little now known about the island petrography, and to suggest

* G. A. F. Molengraaff, Proc. Kon. Akad. Wet. Amsterdam, 1909, p. 141; Deel 23, 1915, p. 1058; and Deel 24, 1915, p. 415.

the huge field lying open for future research in this branch of geology, I have prepared a table of the Pacific islands, already recorded as volcanic; and have entered therein the names of the different rock types, so far as determined by competent petrographers. It is planned to publish this long table elsewhere.

Origin of the lavas.—From twenty-one out of the twenty-eight more important archipelagoes, common feldspar basalt has been reported. Of the remaining seven, the Mariana group is the only one from which any petrographic data seem to have come into print; this archipelago is so little known that it can not yet be regarded as free from basalt. In all, eighty-one islands are said to contain feldspar basalt or its chemical equivalent, diabase or gabbro.

Pyroxene andesite is known to accompany the basalt in nineteen islands and is found in thirty-three others. The two types are not only present in the form of closely associated lava flows; they are also connected by transitional types, called basaltic andesite, andesitic basalt, or olivine andesite. In both respects the dominant Pacific-island lavas are like the dominant lavas in the other ocean basins and on each of the continental plateaus. Their geographical and mineralogical relations suggest that basalt and pyroxene andesite are connected in origin. What is that connection?

According to the only view which seems well supported by physical, chemical, and geological facts, the andesite is best regarded as a direct derivative of common basalt. Under certain conditions, some of the heavier constituents settle out of a column of slowly cooling liquid basalt, leaving a less dense liquid of andesitic composition at the top of the column. The ordinary cylindrical vent of a volcano has the form of such a column; if the temperature is held long enough within the right limits, andesitic liquid is developed in the upper part of the vent, whence intermittent outflows of the new type of lava are easily possible. This hypothesis is important, since it refers to that kind of lava which, next to basalt, is probably the commonest on the earth. If it be correct, the overwhelming preponderance of primitively basaltic material in terrestrial eruptions is all the more evident. The Pacific islands are already known to furnish an excellent field for further testing of this theory.

The archipelagoes also illustrate the close genetic connection between common basalt and many types of lavas which are often described as belonging to the alkaline series. What that connection may be is a difficult problem on which I cannot now enter. Suffice it to say that Hawaii, Samoa, Tahiti, Juan Fernandez, the Hervey islands, and the Fijis have given valuable information on the subject, though in no case is either

the geology or the petrography adequately reported. Like the andesites, the alkaline rocks are found in all the other primary divisions of the globe, so that the petrologist busied in the Pacific is really, here again, engaged on a question of world-wide interest.

Nature of volcanic action.—A few words concerning the mechanism of volcanic action. Its working has been responsible for the formation of nearly all the oceanic islands and there more likely than anywhere else is our understanding of

FIG. 1.

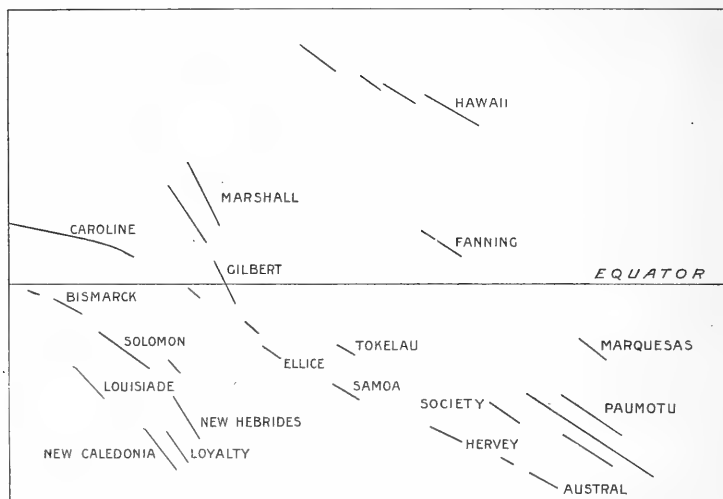


FIG. 1. Trends in the Pacific islands (after J. D. Dana, *Manual of Geology*, New York, 4th ed., 1895, p. 37). Scale 1:100,000,000.

volcanic mechanism to be broadened and deepened. Figure 1 is a copy of J. D. Dana's well-known diagram showing the trends of the volcanic chains on the Pacific floor. An idea of the majestic proportions of each chain of cones is obtained if one remembers that the Hawaiian line of high volcanoes is 300 miles in length. Do these alignments of the volcanic vents directly indicate the step preliminary to all volcanism, namely, the injection of subcrustal lava or magma into vertical fissures opened through the crust? In other words, are the visible vents so many holes long kept open in vertical abyssal dikes or wedges of liquid lava? If so, how is the heat maintained at these openings for thousands of years, in spite of the proved, enormously rapid radiation of heat at the craters?

The Kilauea vent in southeastern Hawaii has suggested an answer to those questions. At that most instructive of all volcanoes there is a lake of molten, surging basaltic rock. (Plate III.) The lake is the top of a liquid column extending deep into the earth; its glowing surface has been almost continuously visible since 1907. Wonderful beyond words is the night view of the exquisitely colored, incandescent billows of molten basalt, as they thrash about the lake. The waves breaking on the lake shore, the ever-varied streaming of the lava, and its periodic, fountain-like uprushes are the effects of the discharge of gas from the earth's interior. Its most important effect, however, appears to be a rapid, convective overturning of the lava, whereby the gas-freed and therefore heavy lava sinks, while fresh, hot lava rushes up to take its place. Such, in brief, is the hypothesis offered in partial explanation of the continuance of activity at Kilauea and it may apply generally. During its years of activity the Samoan volcano, Matavanu, behaved much like Kilauea. It is a great pity that detailed comparative study of these two volcanoes was not made in the field; a unique opportunity has been lost.

Kilauea has further suggested that a volcano is a true furnace, heat being actually generated near the vent through chemical reactions among the constituents of the lava. Through their quantitative analysis of the conditions at the lava lake, Day and Shepherd, of the Geophysical Laboratory at Washington, have confirmed this hypothesis.

How far the maintenance of heat supply at active craters is due to convective overturn, to blowpiping by free-moving gases, or to chemical generation in the lava columns, is a complex and supremely difficult question. According to present knowledge, Kilauea promises a solution sooner than any other vent. Yet, not only should the existing observatory in Hawaii be supported; its scientific product should be strengthened and enriched by close, prolonged observation at the other active volcanoes of the Pacific.

Not less insistent is the question of periodicity, a universal phenomenon in all great volcanoes of the cone-and-crater type. Why is each intermittent, alternately active and dormant? At times the activity of the Kilauean crater is restricted to a quiet emission of gas and vapor from a small hole in a floor of solid lava. For about eight years the crater of the lofty Mauna Loa, twenty miles from Kilauea, was similarly sleeping; until, on the 25th of last November, its molten lavas again appeared, throwing up glowing fountains of liquid basalt, 100 to 300 feet in height. The cause of the intermittency of action for volcanoes in general has been suspected at

these Hawaiian vents, which are surely good strategic points to be kept occupied in a campaign against our ignorance about the interior of this planet.

And, then, the final extinction of a volcano is a problem. If the vent is kept open, directly or indirectly, by the emanation of the earth's primitive gases, why is the end of a volcano's life reached long before the earth's interior has lost more than an infinitesimal fraction of its gaseous matter? Why has Kilauea's activity greatly decreased since 1820, when the missionaries issued the first reports about it? Why is the adjacent Mauna Kea, or the well-known vent at Diamond Head near the heart of Honolulu, without signs of life? Why has Matavanu run its spectacular course in a half-dozen years? Is that vent already extinct or is it dormant? Why did hundreds of volcanic giants on the Pacific floor become long since extinct? The mere phrasing of these queries suggests the ultimate way to answer them; it is by comparative study at the actual vents.

Ultimately the explanation of the volcanic islands must be rooted in a stable theory as to what underlies the ocean floor. The initiation, rhythmic continuance, and final extinction of vents, like the marked alignment of vents on the Pacific charts, are related phenomena apparently applying the preliminary injection of liquid lava into fissures within the solid crust of the earth. Elsewhere I have advocated the view that this primitive liquid is everywhere of basaltic composition. In a subcrustal, basaltic stratum, which is at least locally eruptible, I find most of the matter and energy which have built up the Pacific volcanoes. On this view the volcanoes are the surface expressions of great, molten, basaltic wedges locally thrust up into the solid crust. The pulsing life of a volcano is dependent on the size, gas content, and thermal energy of its feeding wedge. Since each wedge is of limited length, width, and height, ultimate extinction of every volcano is expected. Whatever be the fate of this speculation, the detailed analysis of the Pacific islands is destined largely to control the future stable theory of volcanic mechanism.

Origin of Limestone.

A large proportion of the Pacific islands display no other rocks than limestone. In now passing to a consideration of the third principal kind of islands, I shall first touch on the problem of limestone in general; and then, more in detail, present leading questions about the reefs that have been built by coral polyps and their organic associates.

During the last few years some geologists have come to doubt the prevailing explanation of limestone formations as

being essentially the more or less pulverized remains of shells and skeletons. Emphasis is now increasingly laid on chemical precipitation. The chief agents so far suggested as the indirect causes of the precipitation are two kinds of bacteria. The one kind is that to which the decay of albuminous animal matter is due. In the process these minute organisms generate the powerful alkali, ammonium carbonate, which attacks the calcium salts of sea water and precipitates calcium carbonate. According to this view of limestone formation, the decomposition of the soft parts of animals is more important than is the accumulation of their hard parts.

Drew and others have preferred to attribute the chemical precipitation to the so-called "de-nitrifying" bacteria. Kellerman is now studying the relative significance of the two kinds of bacteria.

These oceanographic researches are exceedingly valuable for geology and should be extended from Atlantic waters to Pacific waters. The field naturalists who wrote the Royal Society report on "The Atoll of Funafuti" of the Ellice group have already showed what a wealth of information on the limestone and dolomite problems can be obtained from a Pacific island, intensively studied.

Coral Islands.

The numerous coral reefs remain for discussion. These are not wholly composed of corals; many other animal and plant species, especially the lime-secreting algæ, are bulky constituents. Nevertheless, the corals are essential in giving each reef that amount of strength which enables it to resist destruction by the surf. For that reason the popular name for the composite structures remains good.

Thousands of them, called "fringing reefs," are growing immediately at the shores of volcanic and other high islands. (See fig. 34, page 185.)

Hundreds of others, called "barrier reefs," are growing at the outer edges of broad platforms that stretch out from high central islands or from the Australian continent. An illustration is seen in Mbengha, one of the Fiji group. (See fig. 38, page 185.)

In Oceania about 200 reefs rim the edges of as many open-ocean platforms, which lack central islands; these are called "atolls." A small example is seen in the symmetrical North Minerva reef, with a longer diameter of about four miles, with a maximum depth in the lagoon of rather more than 100 feet, and, as shown by the soundings, with the usual steep slope outside the reef. (See fig. 23, page 178.) Another

example is the well known Funafuti atoll of the Ellice group. (See fig. 11, page 172.) Much larger are the atolls of the western Paumotus, which rival some of the marvellous atolls of the Indian ocean.

The origin of all three classes of reefs is a fascinating problem, affecting our understanding of the whole intertropical zone of the earth. It has to do with first principles regarding the stability of the earth's crust, the constancy of the general sea-level, the kinds of climate enjoyed or suffered by the organisms of the past, and with the march of organic evolu-

FIG. 2.

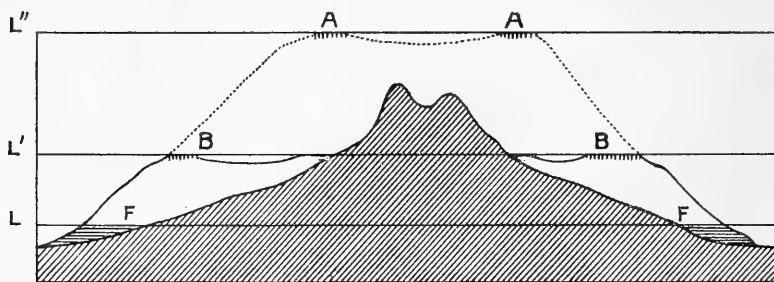


FIG. 2. Composite copy of Darwin's sections, illustrating his subsidence theory. Successive sea-levels at L , L' and L'' ; fringing reefs at F ; barriers at B ; atoll reefs at A .

tion. If there were no other good reasons for systematically studying the gems of the Pacific, this one should lead to speedy action.

Here as usual in productive science, the guide to good observation is theory. The half-score of theories, so far offered in explanation of coral reefs, differ greatly in strength. I shall not attempt to mention them all but will stress two theories, both of which postulate a recent deepening of the water on shoal or island wherever atoll or barrier reef is found. Such deepening may occur in two different ways. On the one hand, the island or shoal may sink, the sea-level remaining sensibly constant. On the other hand, the general sea-level may rise, the shoal or island being undisturbed. The first assumption is made in the celebrated subsidence theory of the reefs; the second is made in the newer Glacial-control theory. Each explanation offers hints for future field work. To appreciate their value, we must review the theories themselves. For two reasons they will be discussed in some detail: first, because they relate to a topic which has specially engaged my attention

for a number of years; secondly, because the listing of many questions connected with this one subject will serve to suggest the great number of questions attaching to every one of the major Pacific problems. The latter conception is so essential to a full understanding of the need for systematic exploration, that I trust you will forgive the tediousness of the enumeration.

Subsidence theory of coral reefs.—The older theory is famous because of its masterly presentation by Charles Darwin

FIG. 3.

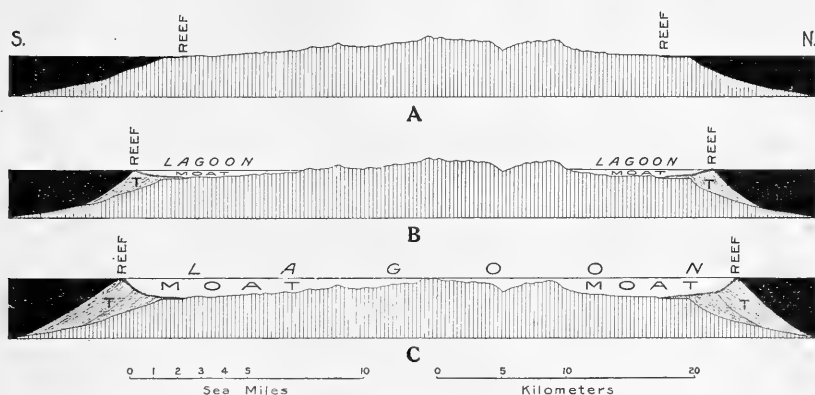


FIG. 3. A. North-south section of the island of Kauai. Water shown in solid black; vertical and horizontal scales the same.

B. Section of the same island after assumed subsidence, with the growth of a (barrier) reef upward and outward on its own talus (*T*). Between the reef and central island is the "moat," the upper part of which is occupied by the waters of the lagoon. The detrital filling of the "moat" is not shown.

C. Section of the same island after further assumed subsidence, with further widening of the "moat" and the formation of an atoll.

and James Dwight Dana. The accompanying diagram, copied from Darwin's book, will serve to recall this conception of reef origin (fig. 2). A volcano, originally built up above the sea-level, *L*, becomes colonized by corals, which quickly construct the fringing reef, *F*. The island is now supposed to share in a slow downward movement of the sea-floor; the corals grow upward to form a barrier reef, *B*, when sea level is at *L'*. Between the reef *B* and the central island is a depression or "moat," filled with sea-water and bottom deposits of the so-called lagoon. When sea-level has reached the position *L''*, the volcano has already disappeared and the atoll, *A*, is all that is left to betray the former existence of the volcanic island.

The same process is imagined for islands, great and small, which represent the high parts of non-volcanic mountains, recently sunk beneath the sea.

As in Dana's corresponding diagram, Darwin's initial island is drawn small and very steep-sided. In order to produce one of the larger atolls by subsidence, a large island with more normal slopes must be assumed. A good type is Kauai of the Hawaiian group. Fig. 3A is a north-south section of this eroded mass of volcanic rock. The section is about twenty miles long. The highest point is nearly one mile above sea-level. The positions of fringing reefs are shown. If Kauai slowly sinks, the reef grows up and outward, on its own talus (marked *T*), passing through the barrier stage of fig. 3B into

FIG. 4.



FIG. 4. East-west section of Suvadiva atoll (southern Maldives of the Indian ocean). Water shown in solid black. The whole section is 33 nautical miles in length; vertical scale is seven times the horizontal. Depths in fathoms.

the atoll stage of fig. 3c. The enormous amount of reef débris which must be washed into the "moat," so as nearly to fill it, should be noted; for no atoll has lagoon water essentially deeper than is shown, to scale, by the thickness of the upper black lines at the lagoons of figs. 3B and 3c.

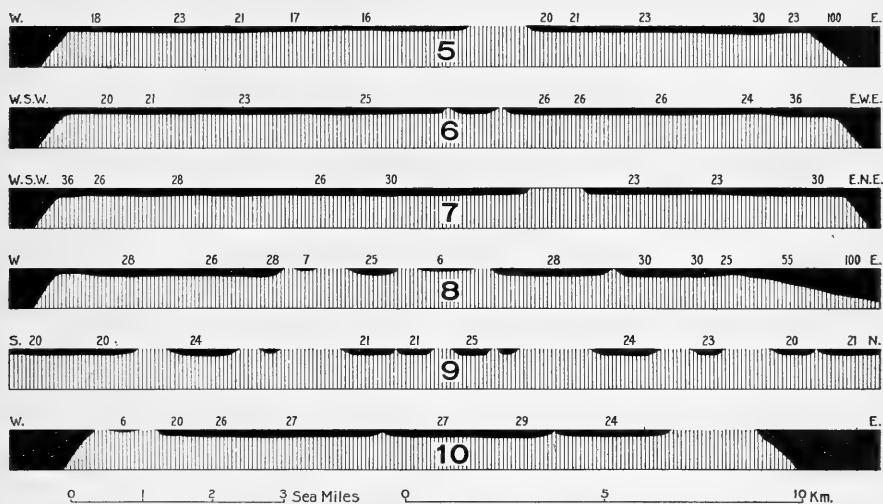
Many difficulties have been urged against this apparently simple theory. The gravest of them has just been suggested. To explain the larger atolls, the subsidence must be reckoned in thousands of feet. As it progresses, reef detritus and other materials are washed into the lagoon, tending to fill the "moat." Neither the rate of sinking nor the supply of filling material for each square mile of the lagoons can be constant for all barriers and atolls. Hence great differences should characterize the depths of reef lagoons. The fact is, however, that each of the world's larger lagoons regularly has an almost constant depth, except in the immediate vicinity of the main reef and of the occasional coral knolls of the lagoon interior. Moreover, the general lagoon depth is almost always between 150 and 250 feet and the maximum depth is nowhere significantly more than 300 feet. Figure 4 is a section of Suvadiva atoll in the Indian ocean. The section is a typical one and it illustrates

the flatness of the lagoon floor and the absence of any trace of the "moat."

Figures 5 to 10 are similar sections of other atolls in the Maldive group. Charts and sections of the Pacific atolls have the same general features.

The relative flatness of the lagoon floors, their failure to show depths greater than about 300 feet, and their rough accordance of depth in the Pacific and Indian oceans are

FIGS. 5-10.



FIGS. 5-10. Sections of Maldive atolls, illustrating the flatness and shallowness of lagoon floors, their accordance in depth with rimless platforms, the steepness of the slopes flanking both main reefs and knolls, and topographic unconformity between reefs and platforms. Uniform scales; vertical scale four times the horizontal. Water shown in solid black; rocks, including reefs, are lined.

5. Tiladummati atoll, through Nekurandu island.
6. Miladummadulu atoll, through Dureadu island.
7. Miladummadulu atoll, through Maswataru island.
8. Ari atoll, sectioned south of Weli island.
9. Longitudinal section, following the main reef of North Malosmadulu atoll, between Duwafuri and Wadu.
10. South Male atoll, sectioned north of Mafuri.

among the most significant topographic facts concerning the important atolls and barriers. The existing barrier and atoll reefs are really narrow, wall-like structures, from 200 to 300 feet in height. They stand on platforms varying from one or two miles to one hundred miles in width. Each reef is like a

crown laid on a plateau, the surface of which is about 300 feet below sea-level. In fact, multitudes of soundings have suggested independent origins for the Pacific reefs and their respective platforms. Further study at critical localities cannot fail to throw light on this fundamental problem in topography.

Besides that principal query regarding Darwin's theory, there are many others calling for active research on the reefs and islands of the Great Ocean.

1. According to Darwin's diagram above described, a bore-hole, put down on the main reef of an atoll, should pass through many hundreds of feet of material characteristic of a massive reef. Such was the conception of the committee of the Royal Society of London, which therefore sunk an 1100-

FIG. 12.



FIG. 12. Diagrammatic section showing the great amount of a reef's centrifugal displacement which is necessary if the reef continued growth during the subsidence of a normal volcanic island (vertically lined), and if the "moat" were always filled with detritus so as to show depths no greater than those of actual lagoons. In order to match actual conditions (flat lagoon floors) the subsidence is assumed to proceed at a diminishing rate. The line 1-2-3 is drawn too straight to match exactly the actual conditions, but this arbitrary drafting does not essentially affect the usefulness of the diagram.

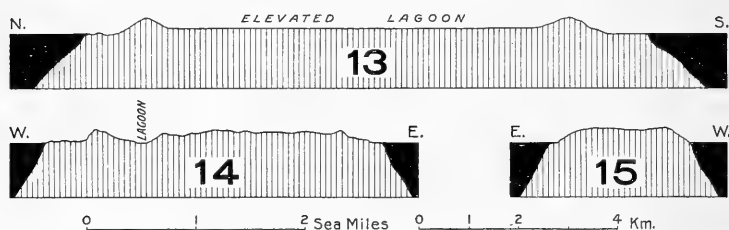
foot boring on the main reef of Funafuti atoll in the Ellice group. Figure 11 is a chart and section of this atoll. The section runs from northwest to southeast and is about nine miles long. Now the log of the boring (made at the point "B") and the drill-core itself both seem to show that reef material *in situ* ceases at the depth of about 150 feet. Beyond that depth the drill passed through limestone which probably represents more or less altered reef-talus, mixed with pelagic shells.

This result suggests the necessity of revising the usual statement of the subsidence theory, if it is to explain Funafuti. During the time required for the filling of the "moat," so that the lagoon floor shall have its observed flatness and small depth below sea-level, the reef should have grown far out on its own talus, as indicated in the accompanying diagram (fig. 12). It

is a section of a sinking island, in which typical levels for a fringing reef (*Fr*), a barrier reef (*Ba*), and an atoll reef (*At*) are indicated, reefs of these types successively appearing at 1, 2, and 3. Since corals cannot form massive reefs at depths greater than 150 feet, a bore-hole sunk on the edge of a large atoll, like Funafuti, must enter continuous talus at a level not more than 150 feet below the sea surface. Hence, the boring actually made at Funafuti does not in any case afford a test between the subsidence theory and its competitors.

What is needed is a series of borings at points situated well inside the atoll and barrier reefs. Several of the Pacific atolls,

FIGS. 13-15.



FIGS. 13-15. Sections of uplifted islands. Water shown in solid black; rocks, including the elevated limestones, are lined. Vertical scale is three times the horizontal.

13. Elevated atoll of Kambara island, Fiji group.
14. Elevated island of Nauru, near the main Gilbert group.
15. Ocean (Paanopa) island, near the main Gilbert group.

like Jaluit, are provided with coral-knoll islets favorably placed for a really valuable test of the subsidence theory through boring.

2. How rapidly is reef detritus carried from the growing, oceanward face of a reef into the lagoon, so as to fill the "moat"? How do the inner slopes of reefs agree with the hypothesis that the lagoon floors have been aggraded and flattened to the extent demanded by the theory? What are the actual slopes of the coral knolls dotted over the lagoons, and what is their bearing on this matter of lagoon filling?

3. What new light can uplifted coral islands throw on the value of the subsidence theory? How can their repeated association with adjacent atolls and barrier reefs be explained? What is the maximum thickness of true reefs in the elevated islands? Figures 13, 14, and 15 are sections, respectively, of Kambara of the Fijis, and of Nauru and Ocean islands near the main Gilbert group; all three have been uplifted.

4. Is there any direct connection between the forms of existing reefs and the Tertiary fragmentation of the Australasiatic

continent? Are the wide bays of Fiji, New Caledonia, and other island groups due to this older drowning of river valleys or to recent drowning, as implied in the Darwin-Dana theory?

5. Is that theory correct in assuming that coral growth has been continuous through the latest geological periods?

This question leads directly to my remaining topic—field problems suggested by the Glacial-control theory, the other explanation of reefs here to be considered. Its more elaborate statement is about to appear in the Proceedings of the American Academy of Arts and Sciences.*

Glacial-control theory of coral reefs.—During a visit to Oahu and Hawaii in 1909, I was impressed with the small area covered by each of their fringing reefs. Since corals grow and add to their reefs with great rapidity, the small width of the Hawaiian reefs means that they are, geologically speaking, very young. The true cause of their youth was unsuspected until I discovered the traces of a glacier at the 12,000-foot contour on the slope of Mauna Kea, the highest summit of Hawaii. The observed markings had a degree of freshness like that of the Pleistocene glacial markings in North America and Europe. The conclusion seems inevitable that the air and sea temperatures of Hawaii, not many thousands of years ago, were lower than the temperatures now prevailing. Since the minimum marine temperature at these islands is 23° C., only 3° above the lowest limit at which corals can thrive, it is an obvious question whether the Hawaiian reefs were not incapable of active growth during the Glacial period. If they did not grow vigorously, the surf would quickly destroy them. By this view, then, the existing reefs are due to post-Glacial colonization of the Hawaiian shallows by corals. Because they have enjoyed warmer water since the Glacial period, the colonists and their offspring have built reefs in spite of the rolling surf.

The open Pacific and Indian oceans nowhere have mean monthly summer temperatures as high as 30° C., and, in much of the coral-reef area of the globe, the winter temperature is no higher than 20° to 26° . Glacialists are becoming steadily more convinced that the whole earth was chilled during the Glacial period. Various lines of evidence indicate that its average air temperature was lower than now by 5° to 10° , if not a little more. As the air temperature falls, that of the sea surface must fall also. In the seas here considered, a drop of 5° to 10° in temperature would cause a partial or complete destruction of the living corals. Thus pondering over the Hawaiian reefs, I was led to hazard the hypothesis that the Glacial period was a time of greatly inhibited reef growth

* See also this Journal, vol. xxx, p. 297, 1910.

throughout the open ocean, the corals then being restricted to the warmest border seas.

Glacialists further assure us that the Glacial period was long, with a total duration of hundreds of thousands of years. One of the most trusted estimates is that by Chamberlin and Salisbury, which is close to 1,000,000 years. If, during a large fraction of that long period, the ocean shores were not protected by living reefs, considerable wave-cutting must have taken place.

Pleistocene glaciation had a second chief consequence. The present depth of the wave-cut benches evidently depends on the position of the sea-surface in the Glacial period. As the facts from Hawaii were further weighed, it became clear that sea-level must have been generally lowered when the huge ice-caps of the Pleistocene were formed. Within the coral-reef areas, sea-level must have been lowered also because of the gravitative attraction of the ice-caps of higher latitudes. Each of these deductions was found to be already anticipated by several authors. The most probable estimate of the total lowering for the tropical seas seems to be about 180 feet.

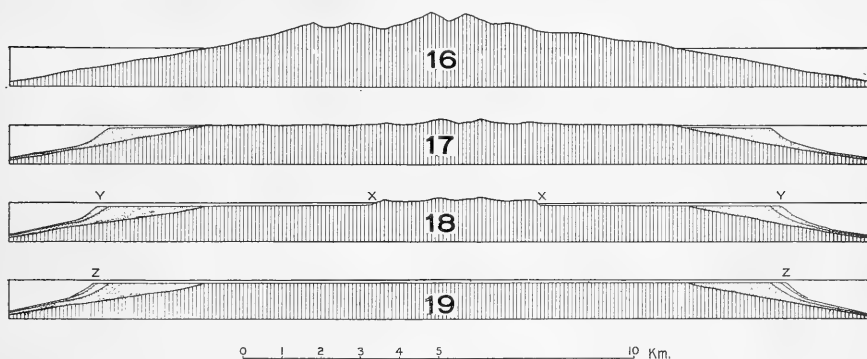
The Glacial period was multiple. Several times its ice sheets waxed greatly and waned greatly. Yet one may well assume that, throughout most of the epoch, waves could successfully attack islands which before had been protected by reefs. For several hundreds of thousands of years the benching proceeded. During some tens of thousands of years, when sea-level was about 180 feet lower than now, the open-ocean surf could cut into the weaker shore materials, at a rate conservatively estimated as from three feet to thirty feet per annum. When it is remembered that oceanic islands and shoals are subject to wave action on all sides, there is no difficulty in believing that many of the less resistant structures, twenty miles or more in diameter, might be completely truncated and smoothed by the waves, during merely the time of maximum glaciation. Just as clearly the waves could make little impression on hard lavas, so that young volcanic islands should to-day have but narrow submarine benches. Narrow or broad, the wave-formed facets would generally be from thirty to ninety feet below the sea-level of the Glacial period and from 200 to 300 feet below the present sea-level. According to the Glacial-control theory, it was on these platforms that the existing, living reefs have grown.

For clearness the ideal cross-sections of figs. 16 to 19 may be reviewed. Section 16 is that of an ancient oceanic volcano. Section 17 represents it after prolonged erosion has lowered its surface, forming a detrital shelf (dotted) all around the island. If not protected by coral reefs in a pre-Glacial period, the waves

would cut a wide bench, with an increase in the detrital shelf, as shown in section 18. If the island rocks were weak, the waves of the Glacial period might destroy the remnant of the island, forming the smooth platform of section 19. Or, if the island were large and the rocks stronger, section 18 might be taken to represent the total amount of wave-cutting possible at the end of the Glacial period. Colonization by post-Glacial corals would lead to fringing reefs at *X*, barrier reefs at *Y*, and atoll reefs at *Z*.

The melting of the ice-caps meant a warmer Earth climate and the re-establishment of marine conditions once more favor-

FIGS. 16-19.



FIGS. 16-19. Sections illustrating the development of barrier reefs and atolls.

16. A normal volcanic island.

17. The same island largely peneplained, with the necessary formation of an encircling embankment of detritus (stippled). It is here arbitrarily assumed that there has been no marine abrasion.

18. The same island extensively benched by the waves, involving some increase of the embankment. Such benching is expected in very old islands which have been exposed to active abrasion, either because of the Pleistocene chilling of the ocean or because of temporary failure of reef protection in pre-Glacial time.

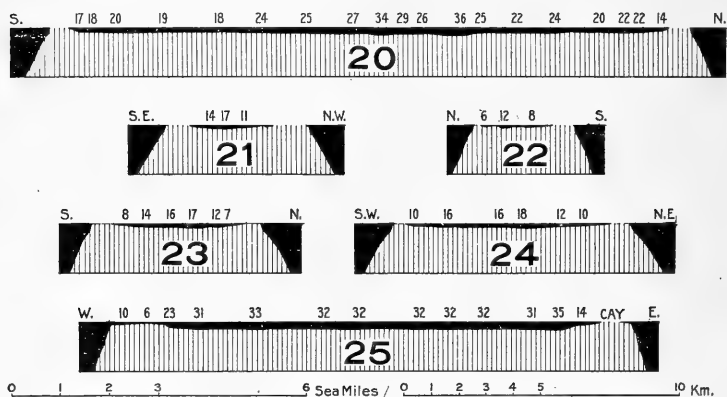
19. Complete truncation of the island by continued marine abrasion, with a slight broadening of the embankment. In many instances this was a stage possibly attained during pre-Glacial periods as well as during the Pleistocene.

In figs. 17, 18, and 19, the size of the embankment, as drawn, corresponds merely to the bulk of purely inorganic detritus. If intermixed reef and other organic material were allowed for, the embankment must be represented as broader. After the abrasion, fringing, barrier, and atoll reefs would be favorably located at *X*, *Y*, and *Z*, respectively. Shifts of sea-level are not shown.

The sections are drawn to scale and are also intended to show the great areal extent of the weak embankment materials, laid down around old oceanic volcanoes in pre-Glacial time. About one-half of the platform represented in fig. 19 is underlain by these materials, which would offer little resistance to the benching surf of the Pleistocene period.

able to coral growth in the tropical seas. It also meant a return of water to the sea, with an ultimate raising of its level by about 180 feet. The positive shift of level must have been slow, while colonization by coral larvæ over large areas is known to be rapid. In most cases the corals began vigorous growth on the platforms, before the covering water reached the depth of about 120 feet, at and below which corals cannot thrive. The larvæ would settle indiscriminately on the platforms, but in general only those situated on the edges of the platforms would form persistent reefs on the large scale. The

FIGS. 20-25.



FIGS. 20-25. Sections of small and middle-sized atolls, illustrating the rule that small atolls are more filled with detritus than those of larger atolls. Water is shown in solid black; rocks, including the reefs, are lined. Uniform scales; vertical scale is five times the horizontal. Depths in fathoms.

20. Peros Banhos, Chagos group, Indian ocean.

21. Salomon islands cluster, Chagos group.

22. Six islands cluster, Chagos group.

23. North Minerva atoll, at $23^{\circ} 37'$ S. Lat. and $178^{\circ} 56'$ W. Long.

24. Wataru atoll, Maldive group.

25. Section through one of the rare cays of Loai ta "drowned atoll," China Sea.

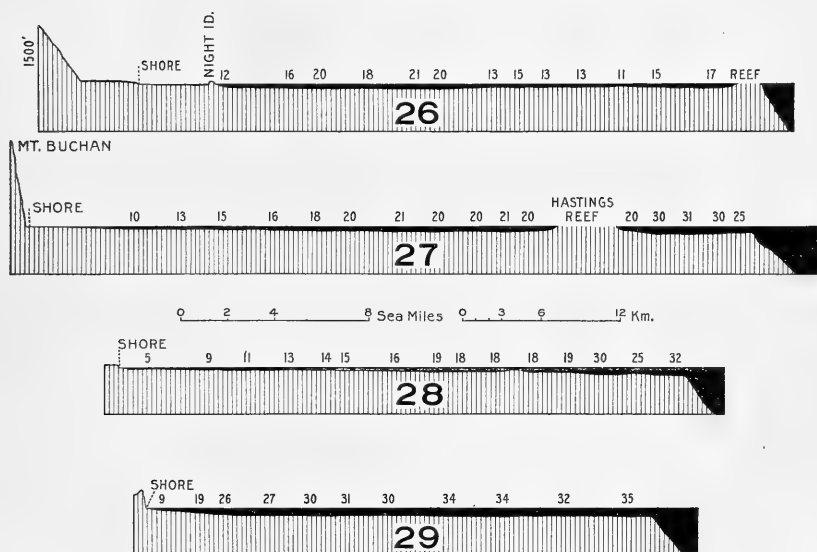
colonies of the interior must be largely extinguished by the platform mud, which is washed over them by waves coming in on all sides. The border colonies, each subject to mud invasions from only two quadrants instead of four, have a great advantage. Once these rimming reefs have grown up to the sea-surface, the danger of death from the platform mud is but slight for the polyps growing on the outer face of the reef. Accordingly, the reef growth is there specially rapid and continuous. Thus it follows that the platforms have generally

become rimmed with growing reefs that follow the edges of the platforms. These are the atolls and barriers of the Pacific and Indian oceans.

The exterior location of atoll reefs is illustrated in figs. 20 to 25.

Exceptionally, small colonies have withstood the fatal mud baths of the platform interiors and to-day form the coral knolls of the lagoons. Since these are normally steep-sided and rise

FIGS. 26-29.



FIGS. 26-29. Cross-sections of the Australian shelf, illustrating the superimposition of the existing coral reefs on a broad platform, which was developed before, and independently of, the growth of those reefs. Water shown in solid black; rocks, including reefs, are lined. Uniform scales; vertical scale twelve times the horizontal.

26. At $13^{\circ} 10'$ S. Lat., through the Great Barrier Reef.

27. At $16^{\circ} 35'$ S. Lat., through the Great Barrier Reef.

28. At $24^{\circ} 30'$ S. Lat., outside the coral sea. The shallowness of the shelf here is explained by Recent, rapid aggradation, due to the local configuration of the coast and by a corresponding abundance of sand.

29. At $24^{\circ} 45'$ S. Lat., outside the coral sea.

from lagoon floors 150 to 250 feet below sea-level, danger of extinction by bottom mud has long been small. Hence many knolls bear luxuriant coral patches.

The lagoons themselves represent platform areas slightly shallowed by a veneer of post-Glacial detritus, shelly deposit,

FIG. 30.

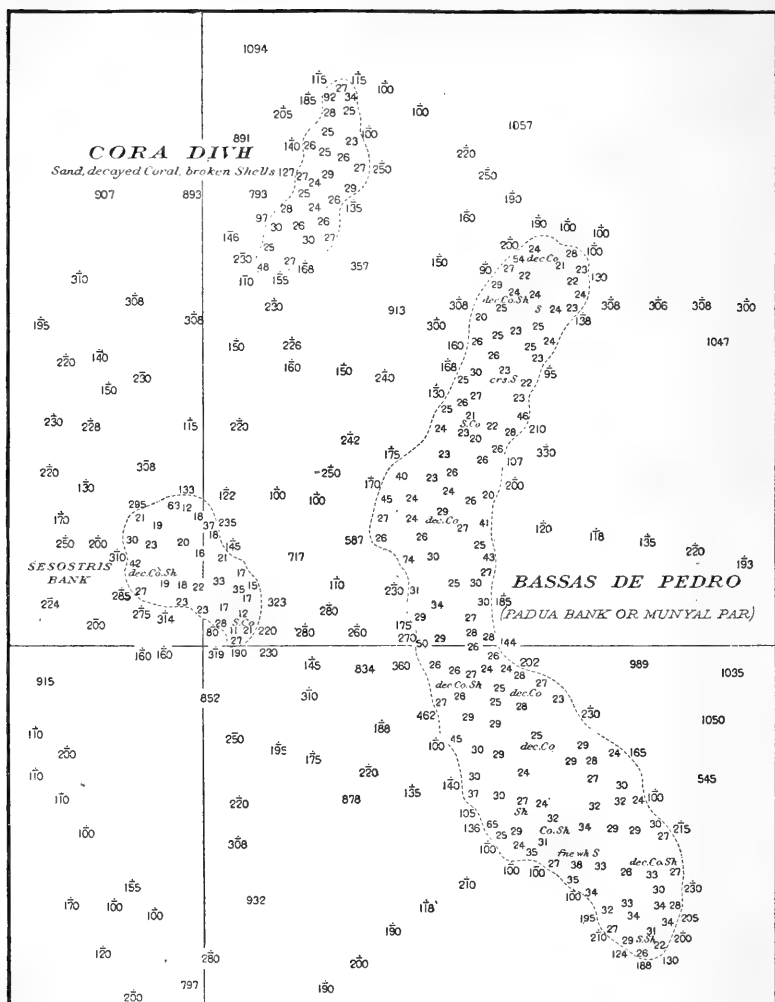
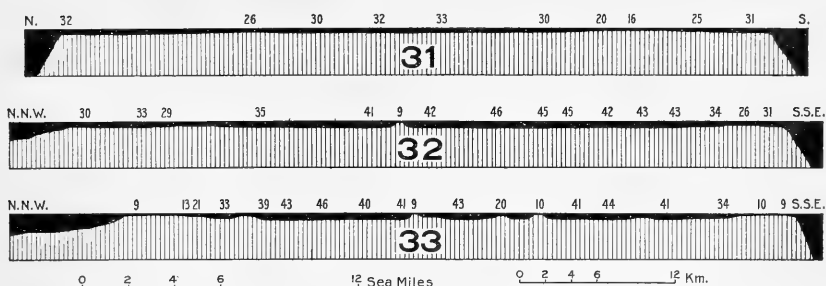


FIG. 30. Chart of banks north of the Laccadive islands, Indian ocean. Scale, 1 : 1,250,000. Depths in fathoms.

and sporadic coral and nullipore growth. We now see why each normal atoll or barrier reef is like a crown, laid on the rim of a wide, flat plateau.

The Glacial-control theory demands that many banks lying outside the coral seas and not affected by post-Glacial movements of the earth's crust, should now be at depths nearly equal to those in the wide reef lagoons. This expectation is amply met by the facts of the admiralty charts. Further, a platform, which extends from the coral-sea area into a region where the ocean water is too cold for coral growth, should show nearly the same depths both in the lagoon of the reef-

FIGS. 31-33.



FIGS. 31-33. Sections of large banks. Water shown in solid black; rocks, including reefs and coral knolls, are lined. Depths in fathoms. Uniform scales; vertical scale is seven times the horizontal.

31. Western end of the Seychelles bank, Indian ocean.

32. Macclesfield bank, China Sea, where rimless.

33. Macclesfield bank, showing the main reef and coral knolls of this "drowned atoll."

covered tract and in the coral-free tract. The Great Barrier of Australia illustrates just such a case, for it seems to be a partial veneer on the warmer part of the 2,000-mile continental shelf of Australia. Figures 26 and 27 are cross-sections of the reef-affected, northern part of the shelf. Figures 28 and 29 are sections of the reefless part of the same great feature. Do they not indicate that the reefs are, in truth, shallow veneers?

Finally, some of the open-ocean banks, even in the coral seas, are reefless. Examples are illustrated in the accompanying chart of the Bassas de Pedro bank and its neighbors in the Indian ocean (fig. 30). The main bank is seventy-five miles long, and, as shown by the soundings, has no reef. The depth on such flat banks varies from 150 to 300 feet, and they seem to be the little modified platforms which were smoothed by

the waves and currents of the Glacial period. Section 31, across one corner of the Seychelles bank (Indian ocean), is thirty-five miles long. Sections 32 and 33, of the Macclesfield bank (China Sea), are drawn to the same scale. For some reason or reasons these banks have not been favorable to the vigorous growth of reefs, though there are reef-covered platforms in the vicinity of each bank. Transitional types are exemplified in the Turpie bank, north of Fiji, on which there is a reef rim only on one side and that covered by 100 and 120 feet of water. The bank is twenty-five miles long, a platform of medium size.

Since the Glacial period closed at a time variously estimated as from 20,000 to 50,000 years ago, all existing reefs should be comparatively narrow. From the known rates of coral growth one can easily calculate the maximum width possible during 50,000 years of growth. The result is to show that the area of a reef on a wide platform must be relatively minute, when compared with that of its lagoon; and that the width of barrier or atoll reef is to be measured in hundreds of yards rather than in miles. In fact, the charted soundings display full evidence of this kind as to the youth of all oceanic reefs.

The problem of the coral reef is thus seen to be, in essence, the problem of the platform. As the Glacial-control theory is specially concerned with the platforms, it suggests many questions relating to the origin of the island platforms in the Pacific; and, again, as the field worker answers them, he accumulates precious facts bearing on the history of the earth's tropical zone as a whole. Some of these questions are here enumerated.

1. What degrees of antiquity are shared by the volcanoes of the Pacific floor? If many of its reef platforms are due to the erosion of great volcanic islands, such erosion must have largely antedated the Glacial period. If the islands were very old, they must have been worn down close to sea-level by constant weathering and stream action. When so reduced, the residual rock must ultimately undergo deep decay. Hence for two reasons—low altitude and weakening of the rocks—very old islands are easily truncated by attacking ocean waves. An important object of future investigators in the Pacific would be to search for evidence bearing on the dates of island formation. There is no reason why volcanic islands may not have been there formed in the ancient periods of Paleozoic and pre-Cambrian time. Observations on the depth to which weathering has affected the integrity of the older islands are needed, as they bear on the question of the speed of wave abrasion.

2. In the many memoirs published on the coral-reef controversy, almost no emphasis has been placed on the point as

to when the oceanic islands began to be well protected by reef corals against the surf. Yet paleontologists tell us that the Madrepোরaria, the reef-builders *par excellence*, were first developed during the Mesozoic era; that very few of the coral species in the present reefs are found, as fossils, in formations earlier than the Miocene; and that practically none seems to have been evolved in pre-Tertiary time. Moreover, a reef's ability to resist abrasion depends on a kind of co-operation among the reef species. Such power of co-operation must come later than the evolution of individual species of corals. Before it was developed to the required degree, the islands were subject to complete truncation by waves during an indefinite number of geological periods. With future researches as to the antiquity of the reef faunas should be associated an investigation of the exact reasons why reef organisms can now resist the fury of the breakers.

3. Even after the co-operative reef fauna was evolved, there is no certainty that it has always continued to protect the islands. A. G. Mayer has recently shown the serious injury done to reef corals by raising the temperature of the water to 35° or 36° C. This is only 6° or 8° above the temperature of the warmest water now bathing most of the coral islands. During at least one Tertiary stage, the earth enjoyed a semi-tropical climate in Grinnell Land, only a few hundred miles from the North Pole. At that time the intertropical area may well have been too hot for vigorous coral growth. If so, the intertropical islands were unprotected and subject to prolonged abrasion by the waves. One of the questions raised is: Does the paleontology of the Pacific islands show a failure of thriving reef corals during the Tertiary period? The need of further observations on the temperature range of living corals and of their reef-building allies is evident and vital.

4. The pre-Glacial truncation of islands was of course accompanied by the formation of offshore embankments. Both phases of this marine work need quantitative scrutiny. To how great a depth can waves of the open ocean erode bed-rock with sensible speed? This is a question not yet answered, for the studies so far made refer to waters like the border seas of Europe, where the ocean swell loses power by running over wide shallows before reaching the cliffs. Direct observations on shores of volcanic islands in the midst of the deep Pacific would be highly valuable.

Similar studies are desirable as to the depths at which the major ocean currents can move bottom sediment. To this action the slow development of the continental and island shelves, so far as they are detrital in origin, is attributed. A required datum is the measured speed of open-ocean currents at varying depths. Such measurement is possible from a

steamer anchored off a Pacific island, which characteristically rises from deep water, like a pier. The commander of the Coast Survey steamship "Blake" has shown that a depth of 12,000 feet is not too great for securely anchoring a vessel. As already noted, continued observation of the Falcon and other volcanic shoals of recent formation, through detailed sounding, should afford direct information as to the speed of marine abrasion in moderate depth. Such determinations ought to control our ideas as to the efficiency of waves and currents in making the great platforms and as to the position of sea-level when they were made.

5. Can one escape the conviction that there was some chilling of Pacific waters during the Glacial period, with some inhibition of coral growth? Systematic investigation of the islands can hardly fail to illuminate this subject, which is highly important in the field of pure biology as well. Closer study of Hawaiian glaciation and paleontological work, such as that indicating a decidedly cooler climate for Java in the Glacial period, are needed. Other possible criteria for the former chilling should be worked out and applied in the island research.

6. The independence of reef and platform in origin is strongly suggested by the break of slope between the two, as shown in the charts now published. Yet many profiles, carefully sounded across each of several reefs and on into its lagoon, would have great value in making still more vivid this significant feature. In the same way detailed profiles of coral knolls, so common within the lagoons, should be plotted from soundings, since they too bear on the origin of the platforms.

More expressly referring to the reefs themselves are a host of physical and biological problems, of which only a few can be mentioned.

1. Considering the obvious difficulty of the subject, new, prolonged studies on the rate of coral growth are urgently required. Yet more complex is the question as to the rates of *reef* growth, for a reef is typically constituted of much material other than coral skeletons.

2. Thorough quantitative work on the proportions of coral and non-coral components in the normal reef has still to be done.

3. Is Gardiner right in holding that reef corals do not thrive in depths greater than 120 feet, because their chief food is made up of green, chlorophyll-bearing algæ? Is light only indirectly necessary to the polyps, since it is an indispensable condition for the life of their plant food?

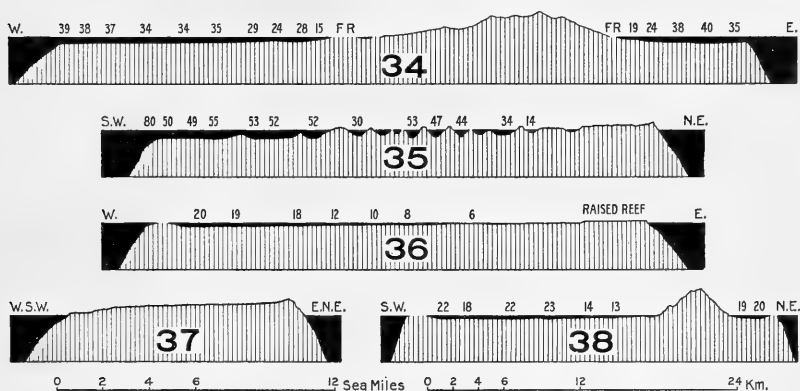
4. What are the physical conditions for vigorous growth of nullipores and other important allies of corals in the work of

reef-making? Are these other species affected by relatively small changes in temperature?

5. Direct observations are needed to test the scope of mud-control, which seems to explain so well the position and shape of each atoll and barrier reef.

6. The Glacial-control theory demands that the oceanic islands should generally have rimming platforms at average depths of about 200 feet, except in the case of those islands that have undergone uplift or subsidence since the Glacial-period. Recent vertical movements are recorded for 72 islands.

FIGS. 34-38.



FIGS. 34-38. Sections illustrating a fringing reef, uplifted islands, and a barrier reef. Water is shown in solid black; rocks are lined. Uniform scales; vertical scale is seven times the horizontal. Depths in fathoms.

34. Rodriguez island, Indian ocean, with a typical fringing reef (FR) and a broad, reefless platform offshore. This island appears not to have been affected by crustal movement in the Recent period.

35. Vavau cluster, Tonga group, an uplifted (probably tilted) limestone plateau, which has been greatly eroded. Note depth of platform on the southwest.

36. Uvea, a tilted atoll of the Loyalty group. The varying depth of the lagoon is a function of the differential uplift.

37. Christmas island, Indian ocean, a strongly uplifted composite of Tertiary limestone and volcanic rocks. Note the absence of a submarine bench.

38. Mbengha island, Fiji group, a typical barrier reef, little or not at all disturbed by Recent crustal movement.

Forty-one of those uplifted have been charted in detail sufficient to allow a test of the new theory. All forty-one either lack submarine shelves entirely or have platforms at levels situated as far above that of minus 200 feet as would correspond to the respective amounts of uplift. Figure 37 is a section of Christmas island in the Indian ocean, an important source of guano. Uvea, of the Loyalty group, is a tilted atoll, as indicated in fig.

36. Stronger tilting is illustrated in the Vavau island cluster of the Tonga group (fig. 35). Contrast with these cases the platform sections of the undisturbed Rodriguez island (fig. 34) and Mbengha island of the Fijis (fig. 38). You have already noted the shelfless condition of the strongly uplifted Kambara, Nauru, and Ocean islands.*

While the existing charts thus seem to support the new theory as it undergoes a very searching test, closer field study of the disturbed islands is highly desirable. Specially significant in each case is the question of the date of uplift or sinking: does it fall in pre-Glacial, Glacial, or post-Glacial time?

7. What are the criteria for recognizing true reef formations in elevated islands? How thick are such uplifted reefs? How extensive? What is their paleontology and what their geological age? What are the criteria for recognizing lagoon deposits and talus deposits? What is the true nature of the "coralliferous limestone," described in the elevated islands of the Tonga, Fiji, Solomon, and other groups? This partial list of leading questions regarding these special islands will suffice to point to the rich harvest of fact and deduction awaiting trained observers who there have a chance to carry on systematic research.

8. Finally, the new theory, like the subsidence theory, should be checked by diamond-drill borings at several appropriate localities in the Pacific islands and lagoons. Plans for them should certainly be included in an organized field campaign.

Review and Conclusion.

You have now followed me through a long discussion of only two of the many extant theories of coral reefs. Analysis of others, like Murray's solution theory, would also suggest big problems for workers in the Pacific islands. The purpose of this paper, however, is not to consider theories or geological problems exhaustively, but to give examples of world questions that press for partial or complete answer in the Pacific archipelagoes. Nearly all of them are taken from only one corner of the field of natural history. Very different would be the emphasis of zoologist, botanist, or anthropologist who might advocate my thesis. Yet I venture to hold that specialists in each of these sciences would unanimously favor a workable plan for the comprehensive investigation of the islands in the Great Ocean. The project is clearly possible, with American support and leadership. It is advisable as the most economical and scientific way of advancing natural science. It promises weighty results. Its accomplishment ought soon to be America's splendid contribution to Pacific civilization.

* See figs. 13-15, page 174.

ART. VIII.—*The Age of the Iron Ore in Eastern Wisconsin*; by T. E. SAVAGE and C. S. ROSS.

It has long been known that a bed of oolitic iron ore occurs in several isolated lenses or patches in southeastern Wisconsin, occupying a position immediately above the Maquoketa (Richmond) shale, and below a limestone of Silurian age. This ore bed is best exposed about 4 miles south of Mayville, near the village of Neda, where its maximum thickness is about 30 feet. From this place it continues north towards Mayville and south towards Iron Junction. Another lens is known to be present a few miles farther southeast, in the vicinity of Hartford. North of Mayville an outcrop of the iron ore occurs about 5 miles east of DePere, in Brown County, and still farther north the iron deposit is known in a few places southwest of the town of Sturgeon Bay. The distribution of this iron ore in Wisconsin has been recently described in a paper by F. T. Thwaites,* to which the reader is referred for a detailed description of the distribution of the deposit.

Many years ago this iron ore bed was well described by Chamberlin,† who correlated it with the Clinton iron ore of the Appalachian region as follows :

“As yet there seems no authentic instance of organic remains having been found in this deposit, although I was shown fossils, said, with undoubted truth, to have been taken from the ore, but they were probably found in the disturbed drift ore, as they were Cincinnati species, specimens of which were ascertained to have been driven up by glacial forces into the mixed mass overlying the Mayville ore bed. We are left, then, without the valuable criterion which fossils afford for determining the age of this important formation. But there is, nevertheless, no occasion for doubt on this subject. Its stratigraphic position fixes its age within very narrow limits. The limestone above belongs to a very low horizon in the Niagara group, and, indeed, it has been regarded by some eminent geologists as belonging to the Clinton epoch, and it probably is the approximate equivalent of the upper portion of the Clinton beds of New York, but as will be seen hereafter, there is no good reason for separating this limestone from the great mass of the Niagara group, with which it is intimately connected. There is a sharp line of demarcation between the ore and the limestone at most points, so that there is no reason for assigning the ore a higher position than the Clinton epoch.”

“While, as already stated, the clay below mingles somewhat with the lower layers of the iron deposit, the ore ‘takes on’ layers

*Fredrik T. Thwaites, Bull. No. 540, U. S. Geol. Survey, 1912, pp. 338-342.

†T. C. Chamberlin, Geology of Wisconsin, vol. ii, 1877, pp. 327-335.

at the bottom, so that its beds are in a slight degree unconformable to those below, which constitutes a reason for not grouping the iron beds with the Cincinnati series."

"Within the limits to which stratigraphical evidence thus confines this formation, there can be no hesitancy in referring it, on lithological grounds, to the Clinton epochs, since that epoch is

FIG. 1.



FIG. 1. Iron ore bed unconformably overlain by Mayville (Early Silurian) limestone, in an old iron pit in Iron Ridge, near Neda, Wisconsin.

characterized from Ohio as far eastward as Nova Scotia, and as far southward as Alabama, by a similar deposit of oolitic iron ore."

Since the above description and correlation of the iron ore in southeastern Wisconsin were made, geologists have generally assumed the Clinton age of the formation, notwithstanding the fact that the definite correlation was based almost entirely upon the peculiar lithology of the deposit, to the exclusion of the suggestive age indicated by the fossils.

In connection with the study of the early Silurian strata in eastern Wisconsin during the summer of 1914, additional information was obtained bearing directly on the age of the iron ore formation in that region. The relations of this bed to the underlying Maquoketa shale, and to the overlying Silurian limestone, so well described by Chamberlin, are well exposed in an abandoned ore pit near the station of Neda, as shown in figure 1. A detailed section of the strata at this place is given below:

Section of strata exposed in an old ore pit near Neda.

Mayville limestone	Feet
4. Dolomite, gray, crystalline, somewhat vesicular, in layers 1 to 4 feet thick	36
A break in deposition.	
Iron ore bed	
3. Iron ore band, hard, non-oolitic	2/3 to 1-1/3
2. Iron ore, oolitic, reddish-brown, in rather even layers, with a thin band of iron coated fragments of shaly material, and iron pebbles near the bottom	25-32

A break in sedimentation.

Maquoketa shale

1. Shale, calcareous, bluish-gray, hard, in layers 3 to 8 inches thick; containing shells of <i>Hebertella occidentalis</i> , <i>Platystrophia acutilirata</i> and <i>Rhynchotrema capax</i>	8-10
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In the vicinity of Green Bay, about 60 miles north of the locality last described, the iron ore bed is well exposed in the gorge near the foot of Cascade Falls, about 5 miles east of DePere. The succession of strata exposed at this place is shown in fig. 2, and described in the following section:

Section of strata exposed at Cascade Falls.

Mayville limestone	Feet
3. Dolomitic limestone, yellowish-gray, in layers 6 to 18 inches thick	30
A break in sedimentation.	
Iron ore bed	
2. Iron ore, oolitic, in places somewhat conglomeratic in appearance, with a shale band about 10 inches above the base, and much iron pyrites near the top	4-1/2 to 5

A break in sedimentation.

Maquoketa shale

Feet

1. Shale, calcareous, hard, in layers 3 to 8 inches thick, some of which are strongly laminated.. 8 to 10

The unconformity between the iron ore and the overlying Silurian limestone is indicated by the uneven plane of contact,

FIG. 2.



FIG. 2. View showing the bed of iron ore at Cascade Falls, 5 miles east of DePere. The iron bed, included between the arrows in the picture, rests unconformably upon the Maquoketa shale, and is separated from the overlying Mayville (Early Silurian) limestone by a similar unconformity.

and by the residual character of the upper part of the iron ore which contains a much larger percentage of iron pyrites than the average deposit. The relation of the iron ore to the Maquoketa shale is an unconformable one wherever this contact is exposed, the iron ore resting on different levels of the Maquoketa shale.

From the bed of iron ore at Cascade Falls the following fossils were collected:

Cf. *Stenaster* sp.,
Cf. *Eurydictya montifera*,
Lingula cf. *cobourgensis*,
Strophomena wisconsinensis,
Dalmanella tersa,
Byssonychia intermedia,
Byssonychia cf. *radiata*,
Pterinea cf. *demissa*,
Liospira sp.

The fossils listed above, taken from the iron ore bed at Cascade Falls, are Maquoketa species. They came from an undisturbed zone one to one and one-half feet above the base of the iron ore bed, where they could neither have been squeezed up from the underlying Maquoketa shale, nor have been carried up into the iron ore by the movement of glacier ice. The occurrence of Maquoketa fossils in the iron ore is interpreted as indicating the Maquoketa age of the bed. A possible alternative interpretation might assume that the fossils were washed by the waves out of the Maquoketa shale, and redeposited with the material of the oolite as the sea in which the latter accumulated advanced over the region. The fact that the surface of the shells present in the iron ore show little evidences of wear, and that no fossils of Silurian age are found in the deposit support the former interpretation.

The middle and lower parts of the iron ore bed contain pebbles of shale or slab-like iron ore, which in places form a conglomerate. Many of these pebbles also contain grains of oolitic iron, and are of the nature of iron concretions of irregular shape, the iron not only having replaced the calcareous constituents, but also having been deposited in the spaces between the grains, forming irregular concretionary structures. Another part of the pebbles appear to consist of fragments of Maquoketa shale that were worked over and deposited by the waves as the sea in which the oolite accumulated advanced upon the area, and later became thoroughly impregnated with iron. Still another part of the pebbles may have been formed by wave action upon the more clayey portions of the sediments during the progress of deposition of the material, the calcareous portion subsequently having been replaced by iron oxide. The fossil shells present in the iron ore bed were originally calcareous and have all been replaced by iron.

The surface of the pebbles, and also of the grains of oolite, has a shiny, varnished appearance. Grabau* has suggested

* A. W. Grabau, Principles of Stratigraphy, p. 57, 1913.

that the shiny character of the surface of the pebble-like concretions in the iron ore bed is due to desert varnish, and assumed that the material of the iron ore bed was transported and deposited in dune-like masses by the winds under arid conditions. The objections to this view are: (1) The iron ore deposit is horizontally and regularly stratified, as may be seen in figure 1, and shows none of the oblique bedding and irregularities of stratification characteristic of wind deposition; (2) The shiny varnished appearance of the pebble-like concretions is due to the iron, which is present not only as a film or rind on the surface of the pebbles, but the larger part of the pebbles and also of the oolite spheres is composed of iron. The surface of the oolite spheres has a varnished or shiny appearance similar to that of the pebbles, and when some of the concentric laminae of the oolite grains are removed, the surface of the inner ones are also seen to have a similar varnished appearance. Concretionary pebbles of iron are found in many places in a zone near the base of the Maquoketa shale, as at Scales Mound, and Kingston, Illinois. The surface of these pebbles in the lower part of the Maquoketa in Illinois has a shiny appearance, similar to that of the pebbles in the iron ore deposit in Wisconsin, yet the same layers in which they occur also contain many shells of marine mollusks, as *Otenodonta fecunda*, *C. obliqua*, *Cleidophorus neglecta* and other species. There seems no stronger reason for doubting the marine origin of the original oolite in Eastern Wisconsin, the calcareous portion of which has subsequently been replaced by the iron, than for considering the lower fossiliferous part of the Maquoketa at Scales Mound and Kingston, Illinois, in which similar iron pebbles occur, as of nonmarine origin.

The senior writer has shown that the lower part of the Mayville limestone of Wisconsin, which immediately overlies the bed of iron ore, corresponds in age to the Edgewood limestone of Illinois and Missouri, which is much older than the Clinton formation in the Appalachian region. Consequently, the iron ore deposit can not be correlated with the Clinton of the east, but is certainly older than the Edgewood formation. The evidence indicates that it represents deposits in local but apparently connected basins (because of the marine fossils) during late Maquoketa (Richmond) time, and after the main portion of the normal marine Maquoketa sea had withdrawn from the greater part of the region farther south in the Mississippi Valley.

The iron ore bed has been referred to by Chamberlin as the "Mayville ore bed," but he applied the name Mayville*

* T. C. Chamberlin: Geology of Wisconsin, vol. 2, p. 336, 1877.

more definitely to the limestone formation immediately overlying the ore. Thwaites and others have referred to the deposit as the "Clinton ore," but inasmuch as it has been shown that this formation is much older than the Clinton of New York, this name is no longer appropriate. Since the iron formation is well developed and best exposed in the vicinity of Neda (the present name for the old station of Nye), near which place the ore has been worked most extensively, the name "Neda Iron Ore" is proposed for this formation.

University of Illinois, Urbana, Ill.

ART. IX.—*A Petrified Palm from the Cretaceous of New Jersey*; by EDWARD W. BERRY.

SOME years ago I described* the remains of a fan palm from the Upper Cretaceous (Magothy formation) of New Jersey and Maryland. The material consisted of fragmentary rays imbedded in the sandy clays and were, in their manner of occurrence, exactly comparable to similar materials found in littoral and alluvial deposits now forming in the estuaries and lagoons bordered by palmetto thickets along the Florida coast. They are also comparable to the similar sandy clays containing masses of Sabalites found in the last shallow water phase of the Apalachicola group from Florida westward to Mississippi.

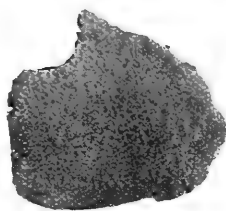
The Upper Cretaceous foliage material was poorly characterized and not very convincing to botanists unfamiliar with the evidence relied upon in determining the botanical affinities of remains of this kind. Subsequently I collected the petrified remains of palm wood from the outcrop of the Magothy formation at Cliffwood Bluff on Raritan Bay, N. J., a locality within a mile of the pits of the Cliffwood Brick Company, where the palm rays are very abundantly preserved.

While it is impossible to affirm that the petrified wood and the leaves represent the same species this is not at all improbable, and whether this be true or not the presence of undoubted palm wood in these deposits tends to confirm the identification of palm leaves at this horizon.

Remains of palms are now well known from scattered localities of Upper Cretaceous age in both America and Europe, and fossil fruits referred with considerable probability to the palms

* Berry, E. W., *Torreya*, vol. v, p. 32, figs. 1, 2, 1905.

FIGS. 1-4.



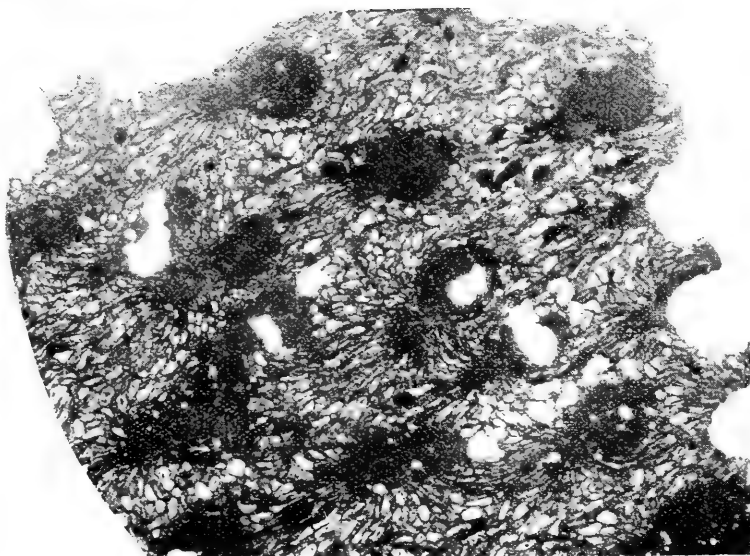
1



2



3



4

are described by Fliche* from a somewhat earlier horizon than either wood or leaves (cénomannien inférieur) in France (Sainte-Menehould). A number of species of palm based upon the petrified wood are also known from the Upper Cretaceous. All of these with the exception of a single form described recently by Stevens† and coming from a much higher horizon in the Cretaceous than the Cliffwood plant, are confined to European localities, and none of the latter are older and most of them are younger than the Cliffwood form.

The present material is therefore of considerable interest because of the rarity of palm wood at such an early horizon, its almost total absence from North America at these horizons, and also because it serves to corroborate the identification of fragmentary leaf-remains in this and synchronous formations—the latter always more common and widespread than wood with structure conserved.

The Cliffwood material comprises fragments of a trunk of considerable size with an indicated diameter of at least 15 cm. The preservation is not especially good since the wood is ferruginized and the tissues have been preserved by their impregnation with tiny spherules of limonite. For this reason the following description is somewhat incomplete, but sufficiently detailed to demonstrate the botanical nature of the material and to render possible the identification of any future occurrences of this form.

Petrified palm wood has been known since the early days of paleobotany. First described under the term *Endogenites*, it was afterwards referred to the genus *Palmacites*, proposed by Brongniart. Schenk, who was a very active student of fossil woods, proposed the comprehensive genus *Palmoxylon* to include all fossil palm woods since the well known similarities of monocotyledonous anatomy render generic discrimination very difficult, if possible at all in the present state of our knowledge of recent palms. Schenk's genus has been universally adopted by subsequent workers in this field—the two most active of whom have been Felix and Stenzel. The latter author in a relatively modern work (1904) has brought together an account of all fossil palm woods known to him. This is fairly complete, but overlooks the Cretaceous species described by Crié from the Turonian of France.‡ According to the usage just mentioned and because it cannot be demonstrated that the wood represents the same species that is represented by leaves in the Magothy formation, the present form may be described as

* Fliche, P., *Études sur la Flore Fossile de l'Argonne*, Bull. Soc. Sci. Nancy, pp. 153-196, 1896.

† Stevens, N. E., this Journal (4), vol. xxxiv, pp. 421-436, 1912.

‡ Crié, L., Bull. Soc. d'Études Sci. d'Anvers, xxi, 99, 1892.

Palmoxydon Cliffwoodensis, sp. nov.

Diagnosis.—Fibrovascular bundles numerous; small, rounded in transverse outline internally, becoming radially elliptical toward the periphery of the stem, about $.5^{\text{mm}}$ in minimum diameter by 1.0^{mm} in maximum diameter, somewhat variable in size, form and relative position, about the distance of their diameters from one another, as numerous and closely spaced at five centimeters from the periphery as at the outside. No auxiliary (accessory) sclerenchyma bundles present. Stem parenchyma without intercellular spaces; cells very variable in size and outline, usually elongated and in general radiating from the bundles as viewed in transverse section, maximum diameter about $.25^{\text{mm}}$, minimum diameter about $.035^{\text{mm}}$. The vessels are small and elliptical in cross section and are few in number (3 or 4); they are usually seen only in bundles that are dividing preparatory to bending out into the petioles. The pisolitic character of the limonite filling makes sectioning very difficult and usually a part of each fibrovascular bundle is represented by a hole in the section, and even if present the limonite spherules mask the plant structures. Bast fibers rounded in cross section, about $.036^{\text{mm}}$ in diameter, their walls much lignified, making up the bulk of the bundles....
figs. 1-4.

The Cliffwood species has been compared with the descriptions and figures of the following species, an enumeration of which with their occurrences will also serve as a census of the known species based on the petrified wood heretofore known from the Upper Cretaceous:

<i>P. anchorus</i> Stevens	Monmouth formation, Seabright, N. J.
<i>P. Ligerinum</i> Crié } <i>P. Andegavense</i> Crié } <i>P. Guillieri</i> Crié }	Turonian or Senonian of France
<i>P. Boxbergae</i> (Geinitz) Stenzel...	Turonian of France
<i>P. Zitteli</i> Schenk	Campanian of the Libyan Desert
<i>P. cellulorum</i> Knowlton } <i>P. tenue</i> Stenzel } <i>P. astron verum</i> Stenzel } <i>P. astron radiculatum</i> Stenzel } <i>P. angiorhizon</i> Stenzel }	Recorded from the Upper Cretaceous of Tlacolula, Oaxaca, Mexico, but of doubtful and probably younger age.
<i>P. variabile</i> Vater } <i>P. parvifasciculosum</i> Vater } <i>P. radiatum</i> Vater } <i>P. scleroticum</i> Vater }	Found in the Oligocene <i>Phosphorit-lager</i> of Brunswick, Germany, and believed to have been reworked from the Emscherian Cretaceous, but original occurrence not conclusively established.
<i>P. Cottae libycum</i> Stenzel	Fayum, Egypt (probably Tertiary in age).

The Cliffwood form is distinct from all of the foregoing. In general appearance it is most like *P. scleroticum* Vater, especially in the distribution and general proportions of the bundles, in the nature of the parenchyma and the bast fibers. The latter species is distinguished by its larger vessels and by the presence of auxiliary sclerenchyma bundles throughout the groundmass.

About a dozen Upper Cretaceous species of palms have been described from leaves or fruits both in Europe or North America, showing the apparent suddenness with which they appear in the geological record at widely scattered localities.

Johns Hopkins University, Baltimore, Md.

EXPLANATION OF FIGURES.

FIGS. 1 to 4. *Palmoxylon cliffwoodensis* Berry, sp. nov., from the Magothy formation at Cliffwood Bluff, N. J.

FIG. 1. Transverse view of a fragment of stem, nat. size.

FIG. 2. Same, times 2.

FIG. 3. Longitudinal view of a fragment of stem, nat. size.

FIG. 4. Microphotograph of transverse section, times 20.

ART. X.—*Plaster of Paris and the Effect of Foreign Substances.* From Experiments in the laboratory of Paleontology, University of Michigan; by EDWARD L. TROXELL.

CONTENTS:

Introduction.
Pure plaster briquets.
Colored plaster.
Adhesives—Dextrine.
Gum arabic.
Glue.
Shellac.
Waterglass.
Magnesium plaster.
Summary.

Introduction.

PLASTER of Paris is a very essential article in the vertebrate paleontologist's laboratory. It has two chief uses: first, for making casts and restoring parts, and second, for mending broken bones by cementing the pieces together. It is frequently combined with other substances in order to increase its hardness, strength and durability. Some of the materials commonly used are glue, gum arabic, dextrine and shellac. The first three, which are soluble in water, are sometimes put into the original mixture, hardening with the plaster; or they, like the shellac, may be applied to the surface of the plaster after it has set.

Experiments have been carried on with these various compounds to determine if possible the best material for each purpose. Over four hundred briquets were made and tested for their tensile strength. They were also examined as to their physical characters, because the color, smoothness, surface hardening, adhesive strength and permanency are at times as important as the strength. The results derived from the tests of strength can well be shown in many cases by the curves which indicate the trend of the varying mixtures. The briquets were made each with a cross section of one square inch, therefore the force necessary to break a briquet is equivalent to the strength of the plaster per square inch.

I am indebted to Professor Charles W. Cook and Doctor J. S. Laird for valuable suggestions and to Professor E. C. Case, who very kindly gave me the use of laboratory materials and facilities.

Pure Plaster Briquets.

It was surprising to note the very high tensile strength of pure plaster. It frequently held 500 pounds, and in one case

a briquet withstood a force of 619 pounds before breaking. The average for the pure plaster briquets, 72 in number, was a fraction over 400 lbs.

An important factor contributing to the strength of these briquets is the ease with which pure plaster mixes with pure water, allowing a minimum of water and thus producing a more dense substance. Foreign ingredients in the plaster such as coloring matter, or in the water as glue or gum arabic, hinder very greatly the mixing, and demand a greater amount of water. Briquets, in which a minimum of water was used, which were made of plaster so stiff that it could support its own weight and which had to be packed into the molds, averaged at least a hundred pounds greater strength than those in which an excess of water was used. This is an unfortunate condition since it is essential in casting that the mixture be liquid enough to pour.

An analogy has been pointed out between anhydrite and plaster mixed with a minimum of water and between gypsum and that mixed with an excess of water. In the one case they are more nearly anhydrous, are stronger, and perhaps more liable to alteration, passing over toward the other extreme of calcium sulphate compounds represented by gypsum, which in turn is not so strong but is known to be more stable. This analogy may be only fanciful. The chief reason for the weakness of the excess water plaster is due to its additional porosity. The space occupied by the additional water is left vacant when the plaster dries out.

Plaster of paris is most soluble at a temperature of 80° C. It is also found to mix more readily with water at about this temperature, therefore it is possible to use a smaller quantity of hot water, thus producing a more dense mixture. This was shown experimentally by tests which gave an average of over sixty pounds per square inch more for the plaster mixed with hot water.

Only a temporary weakening is noticeable as a result of soaking briquets in water. The strength is decreased by at least two hundred pounds if they be soaked in water and pulled while wet. On the other hand, briquets when dried thoroughly after this treatment seemed to give as high or a higher test than others made under the same conditions but not again soaked in water. In one experiment on twelve briquets, those of even number, put in water five and one half hours and then dried, averaged nine pounds per square inch stronger than the odd ones kept dry. In another case four briquets soaked and redried averaged each thirty pounds greater strength than four dry ones. However, in still another case four soaked briquets gave tests averaging nineteen pounds less than those which were not treated.

Retempering.

After plaster or cement has started to set and before the setting is final it may be mixed again, a process called "retempering." To a certain extent this can be done without lessening the strength of the material. In plaster of paris there is really no true initial set, since the process is a continuous one varying only in the degree to which the chemical action has taken place. Even though the crystals are well started in the process of formation, they may be broken apart and disturbed without harm provided there is enough liquid plaster left to cement the fragments together. Plaster once started to set hardens very rapidly after being disturbed, because each crystal already formed furnishes a nucleus around which the mass rapidly accumulates. A quick-setting plaster may therefore be made by mixing in the dust ground from a piece of set plaster, thus supplying the nuclei.

Experimentally retempering gave the following results: Plaster, remixed after standing forty minutes, showed a higher tensile strength than that which had stood a period of ten minutes. Neither was quite as strong as that which was retempered after twenty minutes. Forty minutes was about the limit, for at fifty minutes the mixture set so rapidly, after being disturbed, that it became hard and brittle before it could be put into the molds. It apparently matters little how long the plaster has stood provided it is soft enough to permit of remixing.

Retempering finds its practical application in the use of plaster as a cement where it is to be used little by little. A mixture of gum arabic and plaster may be useful, roughly, for a half hour, but if glue be added in a large proportion it may stand for days and still be available for use. In this case it is probable that the plaster does not function as an adhesive, but merely as a filler forming a body for the glue.

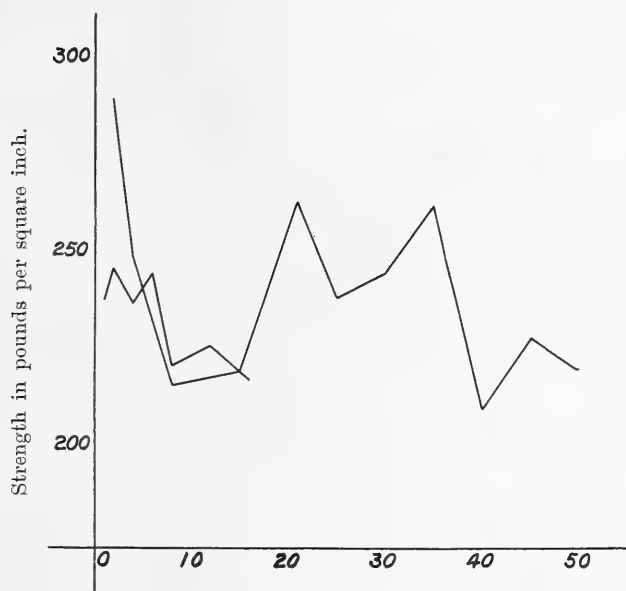
*Colored Plaster.**Effect of Coloring.*

Briquets made up partly of coloring material are necessarily not so strong as those of pure plaster, for the adhesive and cohesive properties of the pigment are not so good, and further the small foreign particles interfere with the growth of the interlocking crystals of the plaster.

The experiments to determine the variation of the strength with the amount of coloring matter gave two curves (fig. 1), one for raw sienna and the other for bone black. These curves, though irregular, show a certain similarity of trend and in

some parts they almost coincide, suggesting a peculiar effect of coloring matter when mixed up in a certain definite proportion. The relatively lower position of the bone-black curve may be due to the greater weakening effect of that substance on plaster or may in part result from the manner of mixing or a greater quantity of water. The curves are roughly convex upward, which indicates that the decrease in strength is

FIG. 1.



Parts of coloring in 300 of Plaster of Paris.

FIG. 1. Curves showing the influence of coloring materials on plaster of paris, based on the record of 67 briquets. Upper curve raw sienna, lower bone black.

accelerated with a constant increase in color. What the course of the curve would be with a continuation of the series is a matter of speculation, but it is probable that it would descend quite rapidly.

The dependence of the strength of these briquets upon the amount of water necessary in their making, is a factor to be considered. But whether it is the coloring itself which weakens the plaster or the greater amount of water which the coloring requires does not matter, for the result is the same and points back to the same ultimate cause.

The sienna curve is based on the tests of 48 briquets, the bone-black curve on twenty-one. Since the change in color is not in proportion to the amount of coloring matter used, in a very dark mixture the addition of a considerable quantity of pigment is necessary to make an appreciable change, and the strength of the plaster has to be sacrificed.

Methods of Coloring.

Other devices are sometimes employed to produce the results desired. A veneer of colored plaster mixed with gum arabic may be spread evenly over the surface. A color may be deepened by a final coat of gum arabic alone, for on drying the water seems to bring the color to the surface where it is deposited in the hard outer crust formed by the gum. A liquid color such as an ink may well be used and can easily be applied to the surface. It can be diluted to the desired intensity and it does not destroy the detail of the surface by filling the small depressions. Common paints and stains are frequently used. The latter are especially good because they penetrate more deeply and have but little luster. Brown shellac gives plaster a glossy yellow color. All these have the disadvantage of their limited penetration and if the plaster is cut or accidentally chipped it shows the white beneath.

In a selection of colors it is commonly supposed that mineral pigments are best since they do not deteriorate. Many colors otherwise liable to alteration might be quite permanent in the favorable conditions found in our museums. Lamp black is almost useless because it is so insoluble. Nearly all the shades necessary in the imitation of bone can be produced by the use of bone black, burnt and raw sienna and Venetian red, combined with the white of plaster of paris.

Adhesives.

Dextrine.

Dextrine is frequently used for hardening plaster; the yellow unbleached variety is a very cheap material costing but fifteen cents per pound. When in solution, which is rather difficult to form, it has a coffee color, and mixed with plaster gives a soft yellow. It has a sweet odor and since it is a sugar the solution deteriorates rapidly unless some preservative such as corrosive sublimate or carbolic acid be used.

The tests with briquets show that dextrine in the *original mixture* does not give to plaster a great tensile strength, rather detracting from it in direct proportion to the density of the solution used in the mixing. Plaster, with a one-fourth solution of dextrine, gave for the highest test 175 pounds per

square inch, the next 113, while the third briquet broke while being placed in the testing machine. With a one forty-eighth solution the best briquet gave a 350-pound test, which is little more than half the strength of the best pure plaster briquet.

In contrast to this the tests with pure plaster afterward soaked in dextrine gave uniformly good values regardless of the density of the solution used. (See curves, fig. 2.) The

FIG. 2.

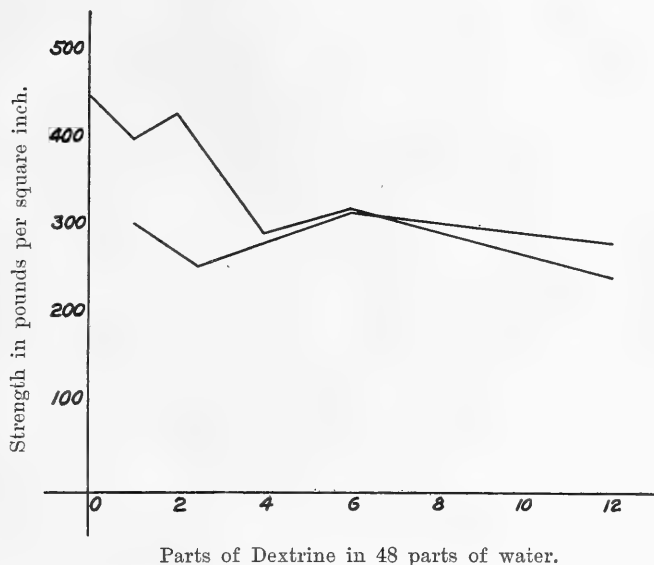


FIG. 2. Curves showing the strength of plaster which had been soaked in a varying solution of dextrine.

strength of a briquet soaked in a one-half solution was 393 pounds; the next highest test was from a one-eighth solution: 342 lbs. The third highest gave a strength of 318 lbs. and had been treated with a one forty-eighth solution.

A thick solution of dextrine leaves a heavy coating on the briquet which on drying cracks and falls away. It therefore does not make as good a surface as gum arabic.

Dextrine, because of its yellow stain, its greater insolubility and its failure to harden plaster effectively, is very little used in the restoration of fossils.

Gum Arabic.

Gum arabic is one of the most useful adhesives in the paleontologist's laboratory and is well-nigh indispensable. It may be

used to harden the fragile bones or the matrix about them; it may strengthen plaster, give it a harder surface and with plaster it is sometimes used as a cement. Since the gum is soluble in water it is much more convenient in the field than shellac, but its very solubility renders it less fit for hardening bones where flour or plaster bandages are to be used in addition. In this case shellac is better because it does not weaken when the wet bandages are applied. Gum arabic is clear and therefore

FIG. 3.

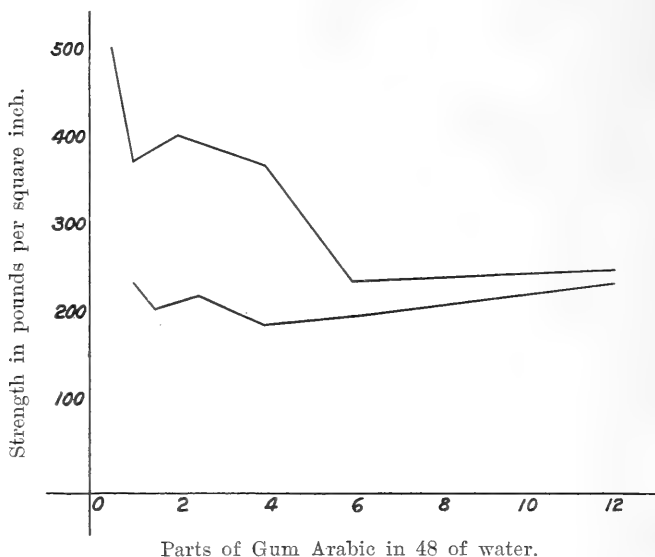


FIG. 3. Curves showing the effect of gum arabic solutions mixed with plaster of paris, based on test of 42 briquets.

does not discolor a surface. Like dextrine, however, it is a sugar and will sour or mildew unless properly sterilized. It is not hygroscopic.

Plaster and gum arabic, combined to form a cement for mending bones, has an advantage over the pure plaster in that the gum adheres more readily to the broken surfaces. This with its ability to give a hard coating constitutes its chief value. Very little strength is gained from the gum which goes beneath the surface; in fact it weakens the plaster. This may be done by prying apart the minute crystals, and drying, renders permanent the same weakening which wet plaster suffers.

Experiments with Gum Arabic.—The use of gum arabic in the *original plaster mixture* makes necessary an excess of

water, for the gum retards its penetration. As has been shown, the additional water detracts from the strength of the plaster and, as in the other cases cited, causes some of the weakening effect which may be ascribed to the gum.

A test of the strength of twenty-four briquets made with gum arabic in the *original mixture* gave the curves (fig. 3). It begins showing the result of a one ninety-sixth solution,

FIG. 4.

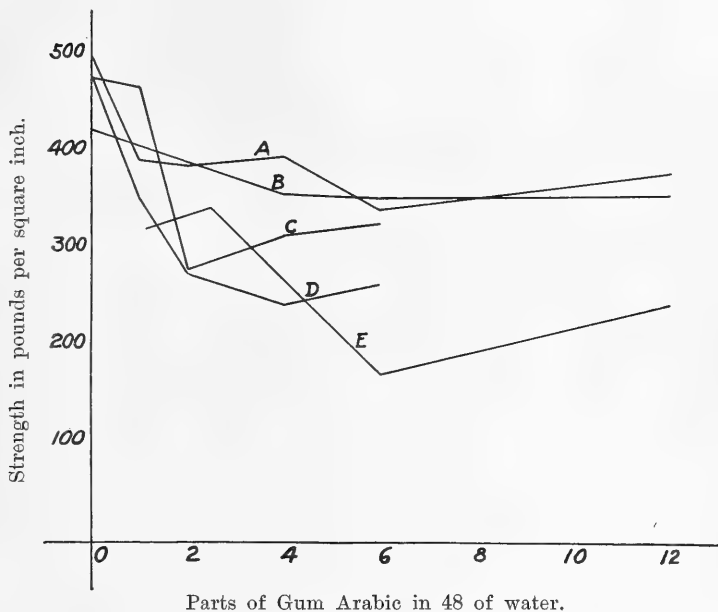


FIG. 4. The effect of soaking the hardened plaster in various solutions of gum arabic. A, B, C, D, each represents 24 briquets, while E is based on the tested strength of 12.

which gave the very high average for four briquets of 509 pounds per square inch. The average for four briquets made with a $1/48$ solution is over a hundred pounds less. The lowest point in the curve is where a $1/8$ solution was used, and the strength is less than half that given by the $1/96$ solution. There is a slight rise to the end of the curve representing the average strength of briquets made with a one-fourth of gum.

There is an irregularity in this curve simulated by one (same fig.) based on the tests of eighteen briquets made earlier. This is probably a coincidence since it is unlikely that there should

be any reason for an irregularity in that particular place. It is significant, however, that both curves show the abrupt fall with the gradual rise at the end, where they agree closely.

Tests were made of the strengthening effect of gum arabic when *applied to the surface* of dry plaster in order to compare with the *original solution* experiments. The results of the surface application of the gum, although indicating a weakening effect in general, yet show that the hard coating may in

FIG. 5.

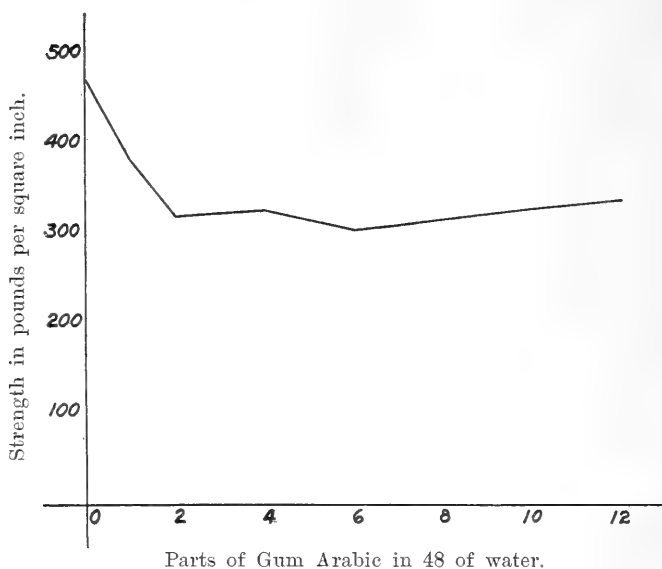


FIG. 5. The average of the curves of fig. 4, which is based on experiments with 108 briquets, soaked in solutions of gum arabic.

the end add a little to the strength. The solutions of medium density seemed to have the poorest effect on the briquets; the one-fourth solution averages nearly fifty pounds less strength than the one forty-eighth, but it is slightly higher than the one twenty-fourth solution.

Five separate curves, based on the tested strength of 108 briquets, show a decided similarity of trend. Four of these curves (A, B, C, and D, fig. 4), representing ninety-six briquets, give results especially dependable. Each set of twenty-four was made up at a single mixing to give an even texture and quality to the plaster; then they were numbered every sixth to insure against local eccentricities. To make the experiment

more complete some of the briquets, aside from those put into the gum solution, were soaked in clear water, while still others were not treated at all. This gave a basis from which to judge more fairly the effect of the gum.

The one forty-eighth solution decreased the strength of the plaster markedly but two parts of gum in 48 of water almost doubled this decrease. From this point less difference was caused by the denser solutions and the average of the curves (fig. 5) runs almost horizontal, the very dense one-fourth solution showing a slight rise. Since only a small increase is noted in the use of the densest mixture, it seems probable that there is a selective absorption and that from the surrounding liquid only a weak solution penetrates.

From the experiments it is very evident that gum arabic weakens plaster of paris, generally as much as one-third and in many cases a half. The effect is greater than apparent, for the surface hardening counterbalances some of the evil and in part makes up the loss.

Since the surface hardening is such an important result of the use of the gum, it has a decided advantage in small or irregular bodies where the surface area is great in proportion to the volume.

The Use of Glue.

In the earlier days of vertebrate paleontology glue was quite extensively used for mending broken bones. In spite of the fact that it is reported to have failed in its purpose it is still used by a number of museums. Its very great strength and convenience gives it an important place in the preparator's workshop. At the present time its use is, or should be, limited to the mending of clean breaks or to the cementing of smooth surfaces where only a thin seam is necessary. In this service it is sometimes combined with plaster which furnishes a body to the glue, rendering it more stable.

The chief objection to the use of glue is that it is hygroscopic, taking up moisture and giving it off again. Where this happens it causes an expansion and contraction which makes it impossible for an adhesive to retain its grip. A sheet of glue, if laid flat on the hand or other moist surface, will curl up rapidly as the under side absorbs the moisture. A stick of carpenter's glue put into cold water did not dissolve, but took up enough water to expand to *three times* its former thickness. It became very pliable and jelly-like but remained tough. It is reasonable to suppose then that glue, exposed to the air with its changing humidity, might take up moisture and prove inefficient.

In contrast to this, glue has some very good qualities: it adheres with great tenacity to wood, or bone, and whether mixed with plaster or not it is very strong and is always ready for use. It is sometimes used as a retarder to the setting of the plaster. Glue if used in mending clean breaks with a thin seam exposing only a narrow edge to the surface, should be very permanent. We have instances of this in mended crockery which has lasted for many decades. In cementing broken bones, if an accurate fit is desired glue is almost essential because it permits a close approximation of the pieces, —and the closer they are the stronger is the seam of glue. Plaster, on the other hand, necessarily occupies a greater space and does not allow the parts of the bone to assume the proper relative position. A coating of shellac over a bone cemented with glue would render it moisture proof, in which case the glue would be the very best adhesive possible.

Experiments in making briquets with glue quite confirm the statement that it cannot be used in large quantities even though mixed with plaster. It requires an excess of water in order to dissolve the plaster; because of this and by reason of the glue itself the chemical action of the setting is not only retarded but the normal formation of the crystals is hindered. The glue makes a very hard crust on the exposed surfaces of the plaster while the inner part shrinks and cracks and is very greatly weakened.

Briquets made with a glue-water solution of one fourth or even down to 1/48 gave very poor results. The highest test showed a strength of 226 pounds while many broke in handling. Other briquets were made using a smaller quantity of glue, one gram to one quart of water. Of sixteen of these twelve were subjected to changes of temperature and humidity; the other four were dried slowly. Of the four the average was 359; two gave a test of 400 pounds each. In contrast none of the other twelve which had been weathered, registered over 277 pounds. Though not an extensive test, this indicates a loss of one third in strength due to the weathering of the glue. All of the briquets were dried thoroughly before testing.

Shellac.

Two kinds of shellac, the white and the yellow, are commonly used by collectors and preparators. The former has the good quality of giving no color but unfortunately it is less soluble. For this it is necessary to have wood alcohol. In the field it is sometimes difficult to secure alcohol, so that there the gum arabic has an advantage over shellac. However, bones which are to be wrapt in plaster bandages should be shellaced rather than gummed in order to make them waterproof.

The glossy finish of shellac makes it unsuitable for coating the mounted specimen except where a very thin solution is used; even this should be wiped with alcohol to remove the excess after it has had an opportunity to soak in. It takes shellac quite a while to dry out thoroughly. One briquet while green had a decided alcohol odor and gave a test of but little more than half that of its fellows, yet it had dried for two or three days.

Shellac gives by far the strongest support to plaster, of all the hardening compounds. It is necessarily limited to the surface but the coating it forms is almost brittle in its hardness. Briquets so treated give the maximum test for plaster. Seven of them soaked in shellac for forty-five minutes or more each showed a strength of over 500 pounds per square inch; while two were recorded registering 621 and 632 pounds. The average for the seven was 572. Those soaked for four or six hours gave but little better results than those soaked about an hour. The only other briquet which showed a strength of over six hundred pounds was one of pure plaster which broke at 619.

Two briquets dipped twice for a period of one half minute each, registered 422 and 442; two others, dipped once for one half minute gave a strength of 413 and 421. The extra half minute, if the results are to be relied upon, gave the first two an average of 13 pounds more strength.

Shellac serves as a very good glue for uniting broken parts. Its strength, adhesiveness and stability are strong points in its favor.

Water Glass.

Experiments to determine the effect of water glass in hardening bones and plaster gave unfavorable results. If a thick solution be applied it gives a smooth glossy surface which, however, soon peels off. Its effect on plaster is to produce an insoluble calcium silicate, at the same time giving off a soluble sodium sulphate which forms fine hair-like crystals on the surface. It detracts from the strength of plaster as shown by tests on briquets, from forty to eighty pounds, and it does not produce a good surface.

Magnesium Plaster.

Magnesium oxychloride plaster has been suggested as a good substitute for plaster of paris. Its crushing strength and tensile strength are high and it has very great adhesive properties: one part of the plaster will hold firmly ten parts of sand. It is somewhat more complicated in its

mixing, being formed from magnesium oxide and magnesium chloride crystals dissolved. It takes several hours to set and is more expensive. In making valuable casts and in restoring the parts of a rare skeleton these objections would be minor matters. In the years to come this may take a very important place in the preparator's work-room.

Summary.

Of all the substances used as a cement, glue is probably the strongest but its usefulness is limited to clean breaks and thin seams. When mixed with plaster it is more stable but should never be used in places where a large space is to be filled.

Plaster and gum arabic make a good cement, but the chief strength is in the crust formed on the surface, while within the plaster is weakened by the gum.

Shellac serves well as a glue, it does not crack and adheres well; it is really quite strong if given time to dry out thoroughly.

The strength of the plaster of paris in nearly every case is reduced by the addition of some foreign substance as a retarder, a pigment or an adhesive. Shellac alone, applied to the plaster, gave it greater strength.

The pure plaster was strongest when mixed with a minimum of water; this can best be done by using hot water.

Probably the most convenient colors to mix in with plaster are bone black, raw and burnt sienna and Venetian red. These pigments satisfy nearly every demand. Liquid colors, as inks and stains, are very convenient but do not penetrate deeply.

Dextrine proved very inefficient but gum arabic is found to satisfy a great many needs of the paleontologist. It can be used to harden fragile bones and the matrix about them; it gives a hard smooth finish to plaster and makes plaster adhere more firmly to bone. It is conveniently soluble in water. In cases where this constitutes a fault shellac may be substituted.

Magnesium oxychloride promises to be more efficient in some special uses than plaster of paris. Experiments with this were not carried out extensively but it might profitably be given a thorough test.

University of Michigan, Ann Arbor, Mich.

ART. XI.—*Note on the Variable Composition of Melanochalcite*; by W. F. HUNT and E. H. KRAUS.

THE literature relating to the unusual mineral melanochalcite is very meager, in fact, our previous knowledge has been restricted to that of a single paper by the late Professor G. A. Koenig.* When, therefore the Mineralogical laboratory of the University of Michigan received from the Ward's Natural Science Establishment several excellent specimens of this rare mineral, a chemical investigation of the material was deemed very desirable.

The material examined was, as far as could be ascertained, from the same general locality as that described by Koenig, namely from Bisbee, Arizona. The lustrous, pitchy black mineral forms bands of varying thickness from a few millimeters to several centimeters, which surround a nucleus of compact cuprite. Chrysocolla and malachite occur in thin thread-like veins penetrating the melanochalcite, and often as a coating upon its outer surface. In order to compare the mineral on hand with that previously described, fragments of the same material which formed the basis of Koenig's article were kindly loaned by the Michigan College of Mines, through the courtesy of Professor A. E. Seaman and President F. W. McNair. While in outward appearance the material previously described and that recently obtained appear identical, considerable difference was noted, however, in their physical properties as well as in their chemical composition. Koenig described his material as giving a coffee-brown streak and possessing a specific gravity of 4.141. The material here investigated gave a decidedly brownish-black streak and possessed a specific gravity of 4.704. The darker streak as well as the higher specific gravity of the specimen analyzed in this laboratory can readily be explained, as noted below, by its higher CuO content.

Sufficient material was on hand to obtain several grams of the jet black mineral entirely free from admixture of cuprite and other foreign matter. SiO_2 was recovered after two evaporations with HCl and corrected by volatilizing with hydrofluoric acid. CO_2 and H_2O were determined in a single operation by heating in a combustion furnace, while a current of dry and CO_2 -free air was slowly passed through the apparatus. The water was caught in a CaCl_2 U-tube while the CO_2 was received in a potash bulb. The increase in weight in the U-tube and potash bulb checked very closely with the loss in weight in the

* This Journal (4), xiv, 404-409, 1902.

porcelain boat. Copper was precipitated as CuCnS , ignited to constant weight, and weighed as CuO . Iron was titrated, and zinc thrown down in a neutral solution as the phosphate.

A chemical analysis following the methods outlined above gave the results indicated in column 2. In column 1 will be found the analysis of Koenig's material, which is here included for comparison.

	1 Koenig	2 Hunt
CuO	76.88	88.94
SiO_2	7.80	4.31
CO_2	7.17	1.78
H_2O	7.71	4.48
ZnO	0.41	0.12
Fe_2O_3	0.07	0.22
	<hr/> 100.04	<hr/> 99.85

While Koenig admitted the possibility of several interpretations of his analysis, he was inclined to believe that the mineral should be considered a basic salt of the very unusual ortho-silico-carbonic acid $\text{H}_2(\text{Si,C})\text{O}_4 \cdot \text{H}_2\text{O}$, in which Si and C replace each other within certain limits. By replacing the hydrogen wholly by Cu and the H_2O partly by CuO , the formula for melanochalcite, according to Koenig, becomes $\text{Cu}_2(\text{Si,C})\text{O}_4 \cdot \text{Cu}(\text{OH})_2$. However, the analysis given in column 2 contains too much CuO and is likewise too low in SiO_2 , CO_2 and H_2O to permit of such an explanation. Moreover, both analyses lend to a much simpler interpretation without calling upon the presence of a complex acid whose existence is doubtful. If ZnO is considered isomorphous with CuO and the small amount of iron is neglected, both analyses can be interpreted as mixtures of malachite, chrysocolla and tenorite, as may be seen from the accompanying tables:

TABLE 1.

		Koenig's Analysis				
	Molecular ratios	Malachite	Chrysocolla	Tenorite	Excess	
CuO -----	0.96583	0.32590	0.12914	0.51585	0.0071	
ZnO -----	0.00506					
CO ₂ -----	0.16295	0.16295	0.25828			
H ₂ O -----	0.42833	0.16295				
SiO ₂ -----	0.12914					
		-----	-----	-----		
		0.65180	0.51656	0.51585, or		
		5.044	4.000	3.992		

Thus in the above table it will be seen that the three constituents are found present in the proportion of 4 parts of tenorite, to 4 of chrysocolla, to 5 of malachite. Expressed in percentages we are dealing with a mixture of 30·8 per cent tenorite, 30·8 per cent chrysocolla, and 38·4 per cent malachite.

TABLE 2.

Hunt's Analysis

Molecular ratios	Malachite	Chrysocolla	Tenorite	Excess
CuO..... 1·1177 }	0·0808	0·0714	0·9669	
ZnO..... 0·0014 }				
CO ₂ 0·0404	0·0404			
H ₂ O..... 0·2488	0·0404	0·1428		0·0656
SiO ₂ 0·0714		0·0714		
	0·1616	0·2856	0·9669, or	
	1·000	1·767	5·983	

In the second tabulation it would seem as though we are dealing with a mixture of the same constituents but this time in the proportion of 6 parts of tenorite, to 1·75 of chrysocolla, to 1 of malachite. Expressed in percentages we would have 68·6 per cent tenorite, 20 per cent chrysocolla and 11·4 per cent malachite.

The above computations are based upon the formula of chrysocolla as usually assigned to it in most texts, namely, CuO.SiO₂.2H₂O. Foote and Bradley,* however, have shown that the composition of chrysocolla is to be considered a solid solution of copper oxide, silica, and water, and that the water content is variable and frequently exceeds the two molecules usually assigned to it. If this view is accepted the excess of water noted in the tabulations could easily be explained. It is also very probable that a portion of this surplus is due to moisture held hygroscopically.

Additional evidence to support the supposition that melano-chalcite is a mixture is to be found in a study of the very fine powder when examined under a polarizing microscope. When viewed between crossed nicols the material appears heterogeneous, being composed of a dark, opaque substance, together with particles which are doubly refractive. A portion of the doubly refractive material extinguishes normally while still other particles possess anomalous colors and are not influenced by a rotation of the stage. This portion is probably chrysocolla under strain. When a drop of very dilute, cold acid is applied to a small portion of the powder spread over an object

* This Journal, xxxvi, 180-184, 1913.

glass, effervescence takes place immediately, while at the same time the extinguishable portion of the doubly refractive material is largely removed from the area affected by the acid. Under such treatment it is but natural to infer that the carbonate, malachite, would be the first to be attacked by the acid, removing this mineral from view and leaving the less readily soluble tenorite and chrysocolla.

These observations were made on the material described in this paper and also on that originally investigated by Koenig. In case of the latter material it should be pointed out that the effervescence takes place with greater vigor, which is in accordance with the above interpretation, inasmuch as there is a much larger proportion of the carbonate constituent present. Koenig thought that his material was homogeneous, but our microscopical investigations upon material used by him did not confirm his assumption.

It would seem, therefore, from a study of the meager data at hand that melanochalcite is not a chemical compound but rather a mixture of tenorite, chrysocolla, and malachite in varying proportions, and as such no definite formula should be assigned to it. If the term melanochalcite is to be retained in mineralogical literature it must, therefore, be interpreted as referring to such a mixture and not to an independent mineral species as thought by Koenig when he assigned it to the material described and analyzed by him.

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SCIENTIFIC INTELLIGENCE.

I. CHEMISTRY AND PHYSICS.

1. *The Extraction and Recovery of Radium, Uranium and Vanadium from Carnotite.*—CHARLES L. PARSONS, R. B. MOORE, S. C. LIND and O. C. SCHAEFER, in a pamphlet of 124 pages, have described the investigations and operations that have been carried on by the National Radium Institute in coöperation with the U. S. Bureau of Mines in connection with the treatment of the carnotite ores occurring in Colorado. Dr. Howard A. Kelly of Baltimore and Dr. James Douglas of New York City, who were interested in the production of radium for use in two hospitals with which they were closely connected, were instrumental in forming the Radium Institute, and this Institute agreed to furnish the sum of \$150,000 for carrying out the work. Preliminary operations were begun in March, 1914, at a plant built at Denver which was enlarged about a year later. The capacity of the

plant is $3\frac{1}{2}$ tons of ore per day and the operations have been eminently successful. Up to October 10, 1915, nearly 5 grams of radium, calculated as element, had been extracted and about $2\frac{1}{2}$ g. of this had been delivered to the hospitals in the form of radium bromide. The market price of radium for two or three years has been \$120,000 or more per gram, and it is estimated that the cost of the radium produced at the works in Denver has averaged \$37,599 per gram. The method of extraction that has been used is novel in some respects, particularly in the employment of nitric acid for the initial treatment of the ore. The radium is almost completely dissolved by this treatment along with nearly all of the uranium and a large part of the vanadium. In the course of the operations for separating and recovering the radium, uranium and vanadium, the nitric acid is finally converted into sodium nitrate, and from this the nitric acid is recovered, so that there is little loss of this reagent. From the nitric acid solution of the ore the radium is precipitated along with barium sulphate by the addition of a barium salt and sulphuric acid. The barium-radium sulphates are then reduced to sulphides by ignition with carbon, the sulphides are converted into chlorides by means of hydrochloric acid and then the chlorides, and afterwards the bromides, are separated by fractional crystallization. After the removal of the radium from the nitric acid solution an excess of sodium carbonate is added to precipitate iron and calcium; then, after the removal of the precipitate, sodium uranate containing some vanadium is precipitated by means of sodium hydroxide, and finally iron vanadate is precipitated by means of ferrous sulphate. The carnotite ore used averaged 2.66 per cent of U_3O_8 and about $6\frac{2}{3}$ milligrams of radium per ton, which is about 1 part in 200,000,000. The publication contains very full details of the operations and includes many illustrations showing the buildings and the apparatus employed.—*U. S. Bureau of Mines, Bulletin 104.* H. L. W.

2. *The Qualitative Separation of Silver from Univalent Mercury.*—N. VON ZWEIGBERGK has studied the method which is generally used by students in detecting silver chloride in the presence of mercurous chloride, and which consists in treating mixtures of the two chlorides with ammonia. It has been known for a long time that the method is unreliable when the amount of silver chloride present is small in comparison to the mercurous chloride, and the investigation under consideration has confirmed this fact. It appears that the reaction of mercurous chloride with ammonia is represented by the equation :



and that the ammoniacal silver chloride solution reacts with the metallic mercury somewhat irregularly, being affected by mass action, as follows :



Some quantitative experiments gave the following interesting results, where double-normal ammonia was used for the reaction,

and the reaction mixture, after dilution to 80°, was shaken for 24 hours :

HgCl taken	AgCl taken	AgCl in solution	
1.1 g.	0.0764 g.	0.0003 g.	or 0.4 %
1.1 "	0.1527 "	0.0030 "	" 2.0 "
1.1 "	0.2291 "	0.0054 "	" 2.4 "
1.1 "	0.3054 "	0.0448 "	" 14.7 "
1.1 "	0.3818 "	0.0938 "	" 24.4 "

The results show that the method fails when the relative proportion of mercurous chloride is large, and that, even when a reaction is obtained, it may give no indication of the amount of silver present. The methods that are suggested to replace this unsatisfactory one consist in the oxidation of the chloride mixture either by bromine or by sodium hypochlorite and nitric acid. The latter dissolves the mercurous chloride quickly in the cold. It may be mentioned here that the process employed in the Sheffield Chemical Laboratory for many years consists in treating the mixture of chlorides at first with ammonia, and then, if no satisfactory reaction for silver is obtained, treating the black residue with a little boiling *aqua regia* until the black color has disappeared, then diluting, filtering, and treating again with ammonia.

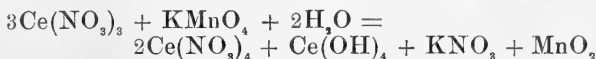
—*Zeitschr. anorgan u. allgem. Chem.*, xciii, 320.

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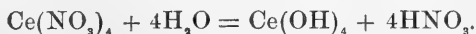
3. *The Diffusion of Solids*.—C. E. VAN ORSTRAND and F. P. DEWEY have made a preliminary investigation upon this subject. They propose to continue the work and to determine the diffusion for minerals and other solids over a considerable range of temperatures and pressures. There is no doubt that the results of such an investigation would be of much interest in connection with geological science. The fact that metallic gold diffuses into metallic lead even at ordinary temperatures was observed by Roberts-Austen about 19 years ago. The present paper deals only with the diffusion of these metals and the authors have confirmed the earlier results as far as the rates of diffusion at somewhat elevated temperatures are concerned, but they find a higher coefficient of diffusion at 100° than was found by Roberts-Austen. An example of the results may be given. A lead cylinder with its end in contact with gold for 54 days at 197° C. showed the following percentages of gold at distances ranging from 2 to 24 millimeters from the surface of contact, where each distance increased regularly to the extent of two millimeters : 0.0187, 0.0145, 0.0109, 0.0080, 0.0057, 0.0044, 0.0030, 0.0020, 0.0012, 0.0008, 0.0002, 0.0001. It is to be noticed that the gold penetrated into the lead to the distance of about an inch. The authors were unable to detect the penetration of lead into the gold for a distance greater than 0.2^{mm}, but it is to be observed that the methods for detecting lead in gold are far less delicate than the assay method for finding gold in lead.—*U. S. Geol. Survey, Profess. Paper 95-G*.

H. L. W.

4. *The Volumetric Determination of Cerium by Means of Potassium Permanganate.*—VICTOR LENHER and C. C. MELOCHE have studied method, which, although it has been known for a long time, has not been accurately described in connection with the conditions required for accuracy. In a neutral solution the following reaction may be expected to take place :



Then the ceric nitrate undergoes hydrolysis, setting nitric acid free, so that the reaction tends to become reversible :



Hence in order to obtain a complete reaction this free acid must be neutralized in a proper manner. However, if a cerous solution is made distinctly alkaline and the solution is either heated or allowed to stand for some time, atmospheric oxygen is absorbed to such an extent that subsequent titration necessarily gives low results. The authors have tried a considerable number of methods for neutralizing the liquid during the titration, and have found zinc oxide or magnesium oxide added in excess in the form of paste to be the best reagents for the purpose. In the case of the use of zinc oxide the titration may be begun in the cold and finished hot, or the whole titration may be performed at a boiling temperature. When magnesium oxide is used it is best, in order to prevent air oxidation, to nearly finish the titration before adding the oxide. The results obtained by the authors, using from 0.16 to 0.3 g. of cerium in about 110 cc of solution, were very satisfactory.—*Jour. Amer. Chem. Soc.*, xxxviii, 66. H. L. W.

II. GEOLOGY AND MINERALOGY.

1. *Men of the Old Stone Age: their Environment, Life and Art*; by HENRY FAIRFIELD OSBORN. Pp. xxvi, 545, with 8 plates and 268 text figures. New York, 1915 (Charles Scribner's Sons).—This very valuable treatise is a fitting associate of Professor Osborn's other great book, *The Age of Mammals* (1910), and in comprehensiveness of treatment brings to mind Obermaier's *Der Mensch der Vorzeit* (1913). No organic being has been more studied than man, living and fossil, and because of the many wonderful finds of the bones and implements of his ancestors in Europe and Asia, going back to the ape-man of Java, there is at present a great wealth of papers and books on this intricate and difficult subject.

There are four ways of determining the chronogenesis of man: by geology, paleontology, anatomy, and human industry. "Geologic events mark the grander divisions of time; palaeontologic and anatomic events mark the lesser divisions; while the successive phases of human industry mark the least divisions" (19).

The author of the book under review studies man not only along these four lines, but in the light of his environment as well. The history is a very long one, with a geologic vista through no less than 520,000 years, and with a reverence for the dead, as shown in burial, which takes us back fully 200,000 years.

With regard to the marked but friendly controversy now going on concerning the man of Piltdown, England, Osborn concludes that this early form is not as old as the majority of authorities say he is. His reason for this belief is that the man is so far advanced in mentality as to exclude him from the earlier part of Pleistocene time. Having taken this stand, he logically goes further and states that, contrary to the prevailing opinion of "some of the highest authorities," he believes the oldest stone implements made by man do not go back more than 125,000 years, or to the time of the third interglacial stage. "Since the Piltdown man was found in association with such implements, it is at once seen that the two questions hang together" (ix). The eoliths, or primitive flints, found in various parts of Europe from Oligocene to Pleistocene times, he holds are now generally admitted to be "mostly of accidental shapes, and there has been little or no proof of their being fashioned by human hands" (85).

Interest in human evolution centers chiefly in the skull and in the brain, and the author, with the assistance of Professor J. H. McGregor, presents restorations of the heads of the various races of men of the Old Stone Age. The controlling principle was to make them "as *human* as the anatomical evidence will admit," and in this the restorations are eminently successful. "No doubt," says Osborn, "our ancestors of the early Stone Age were brutal in many respects, but the representations . . . of men with strong gorilla or chimpanzee characteristics are, I believe, unwarranted by the anatomical remains" (xii).

"From the earliest Palæolithic to Neolithic times it does not appear that western Europe was ever a center of human evolution in the sense that it gave rise to a single new species of man. The main racial evolution and the earlier and later branches of the human family were established in the east and successively found their way westward; nor is there at present any ground for believing that any very prolonged evolution or transformation of human types occurred in western Europe" (489).

Osborn holds that the Piltdown race "was not related at all either to the Heidelbergers or to the Neanderthals, nor was it directly ancestral to any of the other races of the Old Stone Age, or to any of the existing species of man. . . . The Piltdown race represents a side branch of the human family which has left no descendants at all" (144).

"In the whole racial history of western Europe there has never occurred so profound a change as that involving the disappearance of the Neanderthal race and the appearance of the Crô-Magnon race. It was the replacement of a race lower than any existing human type by one which ranks high among the existing

types in capacity and intelligence. The Crô-Magnons belonged to *Homo sapiens*, the same species of man as ourselves, and appear to have been the chief race of the Upper Palæolithic Period up to the very close of Magdalenian times, after which they apparently underwent a decline.

"The arrival of the Crô-Magnons and the introduction of the Aurignacian industry are the first events of the prehistory of Europe to which we can assign a date with any degree of confidence; . . . we may record man of the modern type of *Homo sapiens* as entering western Europe between 25,000 and 30,000 years ago" (260-261).

"The chief source of the change which swept over western Europe lay in the brain power of the Crô-Magnons, as seen not only in the large size of the brain as a whole but principally in the almost modern forehead and forebrain. It was a race which had evolved in Asia and which was in no way connected by any ancestral links with the Neanderthals; a race with a brain capable of ideas, of reasoning, of imagination, and more highly endowed with artistic sense and ability than any uncivilized race which has ever been discovered" (272).

In North America, the Indians were in the cultural stage of the Stone Age when discovered by the Europeans, even though their history may all be of very recent times, but one finds nothing in the book about them.

The printer's work is well done, and the volume is richly illustrated in line work and half-tones. Conspicuous are the many illustrations of the ancient races of men as they appeared in life, and the reproductions of their implements and art, the latter consisting of engravings, paintings in colors and modelling, most of which are found in the caves of France and Spain. All in all, the book is by far the best account in the English language of prehistoric man, and it gives a wonderful vista of the upward evolution of the human family from the speechless animal state into reasoning and speaking man. c. s.

2. *The Permo-Carboniferous Red Beds of North America and their Vertebrate Fauna*; by E. C. CASE. Pub. No. 200, Carnegie Institution of Washington, 1915, pp. 176, 24 pls., 50 text figs.—This very valuable work, the fifth contribution by Professor Case to our knowledge of the life of late Paleozoic time, is a general summary of the known vertebrates of the Permo-Carboniferous strata of North America, the stratigraphy of the beds, and the topographic and climatic environment of the time in the Great Plains-Rocky Mountains area. The author "is convinced that the stage of evolution of the vertebrates, their stratigraphic position, and the accompanying invertebrates indicate that the beds are of Permo-Carboniferous age, and this conclusion is reached with a full knowledge that the evidence from fossil plants is in favor of the Permian age of the beds" (3). More accurately, "it may be roughly stated as from the middle of the Conemaugh to near the top of the Permo-Carboniferous" (95).

In the Permo-Carboniferous beds of North America the author notes the occurrence of 14 genera and 22 species of fishes, 22 genera and 45 species of amphibia, and 49 genera and 75 species of reptiles. Of these, 17 forms occur in Illinois, 3 in Pennsylvania, and 1 on Prince Edward Island, the rest being found in Texas (107), Oklahoma (24), New Mexico (17), and Kansas (2). No less than 18 genera are illustrated as they are supposed to have looked in the flesh.

"The amphibians show the universal carnivorous dentition; the teeth in all are simple, conical, grasping organs with slight power of mastication. . . . Among the reptiles a greater variety of food habits is indicated by the character of the teeth, but so far no form has been discovered which can be reckoned as purely, or even largely, herbivorous. Some are clearly pure carnivores; others may have included some portion of vegetation in a diet composed largely of hard-shelled molluscs" (101-102).

"One feature of the Permo-Carboniferous vertebrate fauna which has, from its striking character, attracted much attention, is the presence of several forms which have developed, to a remarkable degree, spines, horns, excrescences, etc. The number and importance of these over-specialized forms have been exaggerated, because of their peculiarity, but a careful survey of the fauna, especially when an attempt at restoration is made, reduces this feature to a position of much smaller importance than was originally supposed" (111).

"Considering only the region in Texas and Oklahoma, which is typical of all the Red Beds, we may restore in imagination a great flat land stretching away from the Wichita Mountains and the Arbuckle Hills to the east and south, where it joined the ocean waters. The western border of the flat we do not know. The normally semiarid condition of the land was interrupted by incursions of the sea and fluctuations of the climate to more humid conditions. . . . Upon this flat, largely around the pools and streams, lived the wonderfully complex amphibian and reptilian life. The waters swarmed with fish and amphibians, and were constantly invaded by predaceous reptiles in search of food" (147).

"Another thing that must be constantly kept in mind is that the remains are not found in their natural habitat. In only a few cases can it be shown that the animals have been buried near where they lived or died. Rivers or currents in larger bodies of water have borne the carcasses away after death, and in any attempt to picture the natural habitat this must be reckoned with" (148-149).

"The fauna of North America was, so far as the author can see, an isolated one, prevented from any mixture with other groups of animals by an isolation of the continent from Europe" (150). This isolation seems to the reviewer to be due rather to climate (aridity) than to the separation of the continents.

Professor Case's studies have led him to conclude that the evolution of the reptiles was different in North America and

South Africa, although the two widely separated groups are closely related. In South Africa the specializations were clearly toward the Mammalia, while those in this continent tended in the direction of higher Reptilia. c. s.

3. *The Mesozoic and Cenozoic Echinodermata of the United States*; by W. B. CLARK and M. W. TWITCHELL. Monograph 54, U. S. Geol. Surv., 1915, pp. 341, 108 pls.—This valuable and comprehensive monograph brings together all that is known biologically and stratigraphically of the Echinodermata of the American Mesozoic and Cenozoic strata. In Part I the senior author describes the Mesozoic forms, of which there are 117 (Crinoidea, 6 genera and 14 species; Stellerioidea, 7 genera and 9 species; Echinoidea, 35 genera and 94 species). The second part, by Clark and Twitchell, treats of 138 Cenozoic forms (Crinoidea, 1 genus, 1 species; Stellerioidea, 3 genera and 6 species; Echinoidea, 43 genera and 131 species). There are no species in common with either Europe or Asia. All of the forms are well illustrated, so that from now on paleontologists will be able to easily determine their fossil echinoids. c. s.

4. *Upper White River District, Yukon*; by D. D. CAIRNES. Memoir 50, Geol. Surv. Canada, 1915, pp. 191, 17 pls., 2 text figs., 3 maps.—The author here describes the various routes of travel into the upper White River district, Yukon, and the topography, geology, and mineral resources of the country. The pre-Cambrian metamorphics are followed by Carboniferous, Mesozoic, and Cenozoic formations. Copper and gold are the more promising of the economic products.

5. *The Devonian of southwestern Ontario*; by CLINTON R. STAUFFER. Mem. 34, Geological Survey, Canada, 1915, pp. 341, 20 pls., 1 map.—In this stratigraphic report Stauffer describes in great detail the Oriskany and Middle Devonian formations as exposed from place to place in Ontario to the north of Lake Erie and between Michigan and Lake Huron east to Niagara Falls. Everywhere he collected the fossils according to horizons and he now also presents the many local faunal lists. On later pages he gathers all of these together under the caption of "Check list of the Devonian faunas" (228-251).

The Devonian of Ontario is unconformable with the Silurian. In the east the Oriskany sandstone, with the typical New York fauna, is the basal formation, while elsewhere the base is as a rule some member of the Onondaga. The latter loses more and more of its characters as it passes westward from New York and takes on the aspects of the lower members of the Middle Devonian of Ohio. The Marcellus black shale of New York is, in Ohio, the Delaware limestone, which extends into Ontario. On the other hand, the higher members of the Devonian have faunas that relate them to Michigan.

At the close of the book the author discusses the troublesome Detroit River series (and faunas) that on the accompanying map is colored as Silurian but which the Survey officially regards as of Devonian age. The fauna is in the main held to be undoubtedly

ancestral to that of the Onondaga, and yet Stauffer doubts "whether that is sufficient reason to place these deposits in the Devonian as that system is now constituted." He states further that "The lowest layers of the Onondaga in Ohio and Ontario are usually a basal conglomerate. The pebbles of this conglomerate are identical in every way with the underlying dolomites of the Detroit River series from which they were unquestionably derived" (285). The break between these two formations is thought to be great, as the Lucas dolomite, which is from 200 to 250 feet thick, is said to have been deposited during a part of this interval. The reviewer does not doubt the evidence of a break between the Oriskany and Onondaga, nor that the Detroit River series (Flat Rock, Anderdon, Amherstburg) is older than the Onondaga, but he is sceptical about it being so old as Oriskany or Helderbergian.

C. S.

6. *Erosion intervals in the Eocene of the Mississippi Embayment*; by E. W. BERRY. Prof. Paper 95-F, U. S. Geol. Surv., 1915, pp. 73-82, figs. 27-31.—This important paper should be studied by all stratigraphers, because the author shows that the Eocene of the Mississippi embayment is not an uninterrupted and conformable series, but is in the north at least a four-times-broken and disconformable sequence.

C. S.

7. *Arisaig-Antigonish District, Nova Scotia*; by M. Y. WILLIAMS. Mem. 60, Geol. Surv. Canada, 1914, pp. 173, 2 maps.—The author here describes and maps in detail the geology, physiography, and economic products of the Arisaig-Antigonish district of Nova Scotia, an area which preserves one of the longest fossiliferous Silurian sections (3500 feet thick) in North America. The Ordovician, Mississippian, and Pennsylvanian formations are also described.

C. S.

8. *The Stratigraphy of the Pennsylvanian Series in Missouri*; by HENRY HINDS and F. C. GREENE, with a chapter on invertebrate paleontology, by G. H. GIRTY. Missouri Bureau of Geology and Mines. Vol. XIII, 2d ser., 1915, pp. 407, 32 pls., 5 text figs., 1 geologic map.—The authors of this report describe the many subdivisions (8 formations with 33 members) of the Pennsylvanian of Missouri, strata about 1900 feet thick, and their distribution and variation throughout the state (pages 1-255). Compared with the sequence in Pennsylvania, the age of the Missouri strata begins in the upper part of the Pottsville and continues into the lower part of the Monongahela. David White discusses the floras and revises his conclusions published in U. S. Geological Survey Monograph 37 (256-262). The abundant invertebrate fauna (350 species) is described by Girty (263-375), who also lists the American species of *Productus*, 150 in number, and refers 36 of them to *Pustula*, 7 to *Avonia*, and 2 to *Buxtonia*, genera proposed by Thomas in 1914.

C. S.

9. *Fossilium Catalogus, I: Animalia, Pars 9, Stegosauria*; by E. HENNIG. Pp. 16, 1915. Published by W. Junk, Berlin W. 15, price M. 1.50.

10. *Fossilium Catalogus, I: Animalia, Pars 8, Cephalopoda triadica*; by C. DIENER. Pp. 369, 1915. Published by W. Junk, Berlin W. 15, price M. 34.60. We note that J. P. Smith's "Middle Triassic marine invertebrate faunas of North America," Professional Paper 83, U. S. Geological Survey, 1914, is not considered in this catalogue. C. S.

11. *Catalogue of the Meteorites of North America to January 1, 1909*; by O. C. FARRINGTON. *Memoirs of the National Academy of Sciences*, volume XIII; pp. 513, 36 plates. Washington, 1915.—Dr. Farrington has carried through a very important work for the study of meteorites in compiling an exhaustive catalogue of the known falls in North America. This volume has been made possible through a grant from the J. Lawrence Smith Fund of the National Academy of Sciences, and forms a fitting memorial to the early labors of Dr. Smith in this field. From the time of Chladni (1803), various catalogues of meteorites have been issued, that of Wülfing (1897) being the most complete. Unfortunately a still more exhaustive account of all known meteorites (upwards of 600) which was undertaken by Cohen, was interrupted by his death and only one volume completed.

The total number of North American meteorites, recognized as authentic to the end of 1908, is 247. Of these, 161 are irons, 3 of which were seen to fall; 10 are siderolites, and 76 are stones. These falls are taken up in alphabetical order, and the information that has been published in regard to them given with a high degree of completeness; in many cases the original accounts being published in full. The description of each fall is followed by a concise bibliography. Among the numerous points discussed by the author that of the distribution is perhaps the most important. A series of plates gives a graphic representation of the falls in the different states and countries. Numerous interesting points come out which do not, however, all have a like significance. Thus, the Southern Appalachians is a region in which the falls of meteorites have been remarkably frequent; a circle with a radius of 300 miles, and center at Mt. Mitchell, N. C., including nearly one-half of those known in North America. On the other hand the state of Illinois can boast of no fall at all, while Iowa enjoyed the distinction of the three greatest meteorite showers, two of them within 65 miles of each other, and a third 130 miles distant; these are Homestead (1875), Estherville (1879) and Forest City (1890). Other even more notable showers—but not located in time—were those of the iron meteorites at Canyon Diablo and Toluca, in Mexico. Numerous other interesting points are brought out by Dr. Farrington and, indeed, the study of this important subject is certainly much furthered by this thorough and exhaustive volume.

12. *Gems and Precious Stones in 1914*; by DOUGLAS B. STERRETT. Min. Resources U. S., 1914, Part II, pp. 307-346.—A time of business depression always brings a diminution in the

production of gems and precious stones, and it is not surprising that this fact is particularly illustrated in 1914. Even in this country, the important production of sapphires in Montana, and other similar products, showed a large decrease, the only decided increase being in turquoise. Of the last named mineral, two new deposits were developed in Nevada; one in the Hot Springs mining district, Lander County, and the other near the old mining camp of Cortez, not far distant. The mineralogist will find in this pamphlet by Dr. Sterrett many interesting points in regard to the occurrence of beryls, tourmalines, amethysts, and other minerals, although the financial result of the year's work was not striking. It may be added, that the total value of the precious stones in the United States in 1914 was only \$125,000, contrasting with \$320,000 for each of the two preceding years, and \$534,000 for 1909.

13. *The Magic of Jewels and Charms*; by GEORGE F. KUNZ. Pp. 422. With numerous plates and figures. Philadelphia, 1915 (J. B. Lippincott Co.).—This book is a companion volume to "The Curious Lore of Precious Stones" by the same author, and like that treats of the superstitions and fancies that have accumulated about unusual natural objects. The following chapter headings will give an idea of its contents: Magic Stones and Electric Gems; Meteorites, or Celestial Stones; Stones of Healing; Virtues of Fabulous Stones, Concretions and Fossils; Snake Stones and Bezoars; On the Religious Use of Various Stones; Amulets; etc. The book is very well illustrated by means of plates, many of which are colored, and by figures in the text. It is a storehouse of curious information which is presented in an exceedingly interesting manner. W. E. F.

14. *The Mineral Resources of Texas*; by WILLIAM B. PHILLIPS. Pp. 320; 40 plates.—The value of the mineral resources of Texas in 1913 was nearly \$32,000,000, having increased fifteen times in 20 years. In order of importance, measured in cash values, petroleum comes first, followed by clay products and then by coal. The metals are but scantily represented, with the exception of silver, which, for 30 years, has been produced in considerable quantities, chiefly as silver chloride in the Shafter district in Presidio County.

15. *The Mineral Resources of the Philippine Islands for the Year 1914*. Issued by the Division of Mines, Bureau of Science. Pp. 41. Manila, 1915.—This report records the rapid development of gold mining, lode and placer, in the Philippines. The value of the gold produced in 1914 was about \$1,175,000 (2,350,000 pesos), having in five years increased from \$250,000. The value of other metals was small but that of non-metallic products amounted in 1914 to \$1,100,000.

16. *Building Stones of Ohio*; by J. A. BOWNOCKER. Pp. vi, 160; 10 pls. 11 figs. Geological Survey of Ohio, Fourth series, Bulletin 18.—The building stones of Ohio are all of sedimentary origin, including the limestones of the western half of the State

and the sandstones of the eastern half. Both vary widely in character at different localities, but include many excellent kinds, the sandstones particularly taking high rank for building purposes. The special facts in regard to their occurrence at the different localities and their use in the public buildings of the State are given in this volume.

17. *The Peat Resources of Wisconsin*; by FREDERICK WILLIAM HUELS. Pp. xvii, 274; 45 tables, 22 pls., 20 figs. Wisconsin Geological and Natural History Survey, E. A. BIRGE, Director.—The object of this report is to call attention to the extensive peat resources of Wisconsin. The State produces no coal, but it is estimated that there are perhaps 2,000,000,000 tons of peat, an amount which would be one-sixth of the total for the whole United States. The importance of this fact, as bearing upon future conditions, is obvious. The present report describes the distribution of peat over the State, especially the condition of its occurrence at particular localities; also the application of peat as a fuel.

18. *Purchase and Sale of Illinois Coal on Specification*; by S. W. PARR. Pp. 111; one plate, 10 figs. Illinois State Geological Survey, Bulletin No. 29.—The scope of this Bulletin will be understood from the statement that its object is "to present such results and data as have a particular bearing upon the methods of inspection and the purchase and sale of coal by contract."

III. MISCELLANEOUS SCIENTIFIC INTELLIGENCE.

1. *The Development of the Human Body: A Manual of Human Embryology*; by J. PLAYFAIR McMURRICH. Fifth edition, revised and enlarged. Pp. x, 493, with 287 figures. Philadelphia (P. Blakiston's Son & Co.).—This standard textbook has been thoroughly revised and brought into harmony with the latest advances in the subject. Beginning with the germ cells and the development of the external form of the human body, the book describes clearly and concisely the origin and growth of each of the adult organ systems. The illustrations are well chosen and carefully executed. Literature lists of the more important researches are given at the ends of the chapters, and are of much convenience to the reader who desires to pursue the subject more extensively.

W. R. C.

2. *National Academies and the Progress of Research*; by GEORGE ELLERY HALE. Pp. 167.—In this little volume Dr. Hale has brought together a series of interesting and valuable papers reprinted from *Science* dealing in part with foreign Academies, but having special reference to the conditions and immediate needs of the National Academy of Sciences in this country.

3. *Memoirs of the Queensland Museum*; R. HAMLYN-HARRIS, Director. Vol. III. Pp. 346; 30 plates.—This volume opens with

a description of recent additions to the Queensland Museum, with several plates showing the novel exhibits lately installed, for example, that of the kangaroos and wallabies. There follow a series of twenty-two original articles, in part ethnographic and in part zoölogical. Under the latter head are to be noted a series of papers by J. Douglas Ogilby and others on Australian fishes, and also a number of supplements to an earlier memoir by A. A. Girault on Australian Hymenoptera Chalcidoidea.

4. *Edinburgh Mathematical Tracts*.—The following are the titles of six pamphlets recently issued for the use of the Mathematical Laboratory. London, 1915 (G. Bell and Sons).

No. 1. A Course in Descriptive Geometry and Photogrammetry; by E. LINDSAY INCE. Pp. 79; 42 figs.

No. 2. A Course in Interpolation and Numerical Integration; by DAVID GIBB. Pp. 90.

No. 3. Relativity; by A. W. CONWAY. Pp. 43.

No. 4. A Course in Fourier's Analysis and Periodogram Analysis; by G. A. CARSE and G. SHEARER. Pp. 66; 8 figs.

No. 5. A Course in the Solution of Spherical Triangles; by HERBERT BELL. Pp. 66; 23 figs.

No. 6. An Introduction to the Theory of Automorphic Functions; by LESTER R. FORD. Pp. 96; 32 figs.

OBITUARY.

DR. EUGENE WOLDEMAR HILGARD, professor of agriculture in the University of California from 1874 to 1904, died in Berkeley on January 8 at the advanced age of eighty-three years. Born in Zweibrücken, Bavaria, in 1833, he came to this country at an early age, but was later educated chiefly in Germany and Switzerland. He is best known for his investigation of soils, in which he was a pioneer; these were begun when he was State geologist of Mississippi (1855 to 1873). His work on soils embraced both the relation to their fertility and to plant adaptations, and included observations made in the laboratory as well as in the field and forest. He was the author of numerous Government and State reports on agricultural subjects and his labors had practical results of great value to the farming interests of the country. His brother, Julius E. Hilgard (d. 1891), was long connected with the U. S. Coast Survey and its Superintendent from 1881 to 1886.

DR. ARTHUR VAUGHAN, of Oxford University, a distinguished investigator in geophysics and in paleontology, died in December last at the age of forty-seven years. He is best known to American geologists for his detailed and valuable work in zoning and correlating the Lower Carboniferous of Great Britain and Belgium.

PROFESSOR FRANCIS RICHARD BARRELL, who held the chair of mathematics at the University of Bristol, died on December 2, at the age of fifty-five years.

MR. HENRY EELES DRESSER, the English ornithologist, died at Cannes on November 28, at the age of seventy-seven years.

PROFESSOR CHARLES RENÉ ZEILLER, the French paleobotanist, died in Paris early in December.

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[FOURTH SERIES.]

ART. XII.—*Explosive Ejectamenta of Kilauea*; by SIDNEY POWERS.

KILAUEA has not always been a quiet volcano, as it is today, with a lava-lake slowly rising or falling, and only occasionally spilling over the brim. Two catastrophes are recorded in its history—in 1789 or 1790, when violent explosions took place, burying part of an army; and in 1868, when violent earthquakes were accompanied and followed by a sudden draining of the lava-lake, a lava flow to the sea, and a subsidence of the south coast of the island, with the loss of many lives. An examination of the vicinity of the crater shows that these are but the latest of a long series of catastrophic periods. It is the material ejected in 1789 and in the pre-historic explosions that this paper proposes to describe, together with a brief comparison with similar features of the other volcanoes on Hawaii.

The first account of the southern end of the island of Hawaii is from the narrative of Captain Cook's expedition in 1778-9. The region was recognized as being of volcanic origin, but no activity of either Kilauea or Mauna Loa was observed, nor were any traditions of the natives concerning activity reported.

The next visit to the region was by Vancouver in 1794. Columns of smoke were observed rising from Kilauea, and smoke and ashes were so thick at Kapapala that they proved troublesome to Menzies in his expedition up Mauna Loa. Menzies did not report the eruption of 1789.

The eruption of 1789 is described by Rev. Sheldon Dibble. An army under the leadership of Keoua was on its way from Puna to Kau :

"His path led by the great volcano of Kilauea. In the night a terrific explosion took place throwing out flame, cinders, and even heavy stones to a great distance, and accompanied from above with intense lightning and heavy thunder. In the morning Keoua and his companions were afraid to proceed and spent the day in trying to appease the goddess of the volcano, whom they supposed they had offended the day before by rolling stones into the crater. But on the second night and on the third night also, there were similar eruptions. On the third day they ventured to proceed on their way, but had not advanced far before a more terrible and destructive eruption than any before took place, . . .

"The company in advance had not proceeded far, before the ground began to shake and rock beneath their feet, and it became quite impossible to stand. Soon a dense cloud of darkness was seen to rise out of the crater, and almost at the same instant the thunder began to roar in the heavens and the lightning to flash. It continued to ascend and spread abroad until the whole region was enveloped, and the light of day was entirely excluded. The darkness was the more terrific, being made visible by an awful glare from streams of red and blue light variously combined, that issued from the pit below, and lit up at intervals by the intense flashes of lightning from above. Soon followed an immense volume of sand and cinders which were thrown in high heaven and came down in a destructive shower for many miles around. Some few persons of the forward company were burned to death by the sand and cinders, and others were seriously injured, all experienced a suffocating sensation upon the lungs, and hastened on with all possible speed.

"The rear body, which was nearest the volcano at the time of the eruption, seemed to suffer the least injury, and after the earthquake and shower of sand had passed over, hastened forward to escape the dangers which threatened them, and rejoicing in mutual congratulations that they had been preserved in the midst of such imminent peril. But what was their surprise and consternation, when on coming up with their comrades of the center party, they discovered them all to have become corpses. . . . So much like life they looked, that they at first supposed them merely at rest, and it was not until they came up to them and handled them that they could detect their mistake."*

The only other account of activity at this time is a tradition, recorded by Hitchcock,† of an extensive lava flow in Puna about 1789. Perhaps this flow followed the explosive eruptions in the crater.

The main trail from Puna to Kau, over which the army marched, is about 3 miles south of Kilauea. They probably make a trip to the crater to visit a temple at Uwekahuna, but

* Sheldon Dibble, *History of the Sandwich Islands, Lahainaluna, 1843*, p. 65.

† Hawaii and its volcanoes, Honolulu 1911, p. 165.

when they were overcome by the eruption, it was on the trail, not far from Puu Koae, according to Dr. W. T. Brigham, who saw some of the bones near that locality in 1864.*

The eruption which proved so destructive to the army probably was local in character, like the blast which destroyed Saint Pierre in 1902, and may have come from the Cone Crater, near Puu Koae, on the Kau desert southwest of Kilauea. In the vicinity of the Cone Crater there is a very fresh deposit of black ash, thread-lace scoria and lava droplets. This deposit lies principally to the southwest, toward the

FIG. 1.

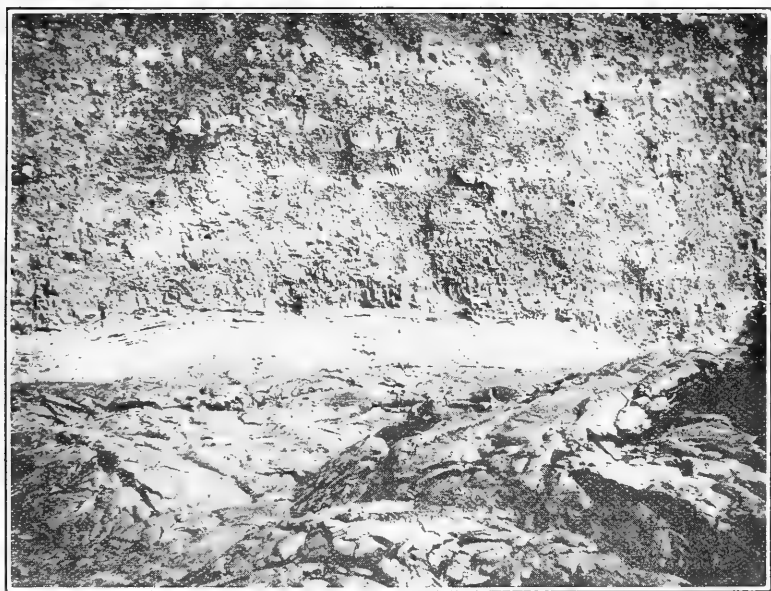


FIG. 1. The ash bed at the base of the cliffs west of Uwekahuna. The base of the section is concealed by the fresh pahoe-hoe lava on the floor of the sink. Photo by H. E. Wilson.

trail in question, and in the direction of the trade winds. If the particular blast came from Kilauea, the configuration must have been very different from the immense pit seen in 1823. The violence of the activity of Kilauea in 1789 is not

*The writer is obliged to Dr. Brigham for information on this mooted point as to just where the army was killed. David Douglas states that the army was on the southwest side of the crater, when the eruption took place, and that the eruption lasted for 7 days. (*Jour. Roy. Geogr. Soc.*, iv, p. 333, 1834.)

minimized in the least by the possibility of contemporaneous activity on the southwest rift-line marked by the 1868 and older fissures.

The ejectamenta of Kilauea are readily divided into two classes: those in the walls; and those outside and on top of the walls. The former are of great age, and only exposed in the faults bounding the main sink; the latter are in part 1789, but mostly pre-historic.

Older Ejectamenta.

The ash-sections in the walls of Kilauea are difficult to find, and more difficult to trace, both because of their similarity to the lava-flows and to the eroded surfaces of these flows; and because of the verticality and inaccessibility of the walls. The most extensive section is at the base of the cliffs, southwest of the Uwekahuna fault-blocks. Another is found at the northeast end of the fault-blocks.

The former section (fig. 1) is exposed to a thickness of only 17 feet and for a length of about 500 feet, at the base of a cliff 170 feet in height. The beds are composed principally of yellow ash with some rock-fragments 1-2 inches in diameter, lava droplets, thread-lace scoria, and a few bombs 6 inches in length. At either end the section dips beneath the floor of the sink. The tilting of the beds probably took place with the faulting at Uwekahuna, as the pahoehoe flow immediately above the ash follows the contour of the ash without varying in thickness.

On the northeast side of the Uwekahuna fault-blocks, above a talus slope, is exposed an unconformity (fig. 2), which appears to be a fault formed during the construction of the dome of Kilauea. Above the unconformity is a bed of ash, varying in thickness from 1-6 feet, and the flows above the unconformity end against the ash. The stratigraphic relation of this section to that above described is difficult to determine on account of the Uwekahuna fault-blocks which conceal the conformity.

A generalized section of the ash beds as seen in fig. 2, where they rest on a horizontal surface of thin pahoehoe flows, shows coarse and fine ash with fragments of scoria and basalt 1-3 inches. This bed of ash continues around the north wall of the sink, at a height of about 35 feet above the floor. The character of the material changes and the thickness is variable. The fine ash is replaced by scoriaceous lava fragments as well as fragments of rock, until on the north wall of the sink, near a 2-foot dike, the ash has become a red scoriaceous breccia, 5 feet thick. Beyond the first dike the breccia loses its identity

and probably has its continuation in one of the red lava-flows seen about 20 feet above the floor.

Other ash sections must occur in the walls of Kilauea, but they have not been carefully examined.

Younger Ejectamenta.

The younger deposits of explosive material are found everywhere in the vicinity of Kilauea: on the road to Hilo, 6 miles to the east of Halemaumau; at the Keauhau Pali, 8 miles south; near the Halfway House on the road to Kau, 8 miles

FIG. 2.

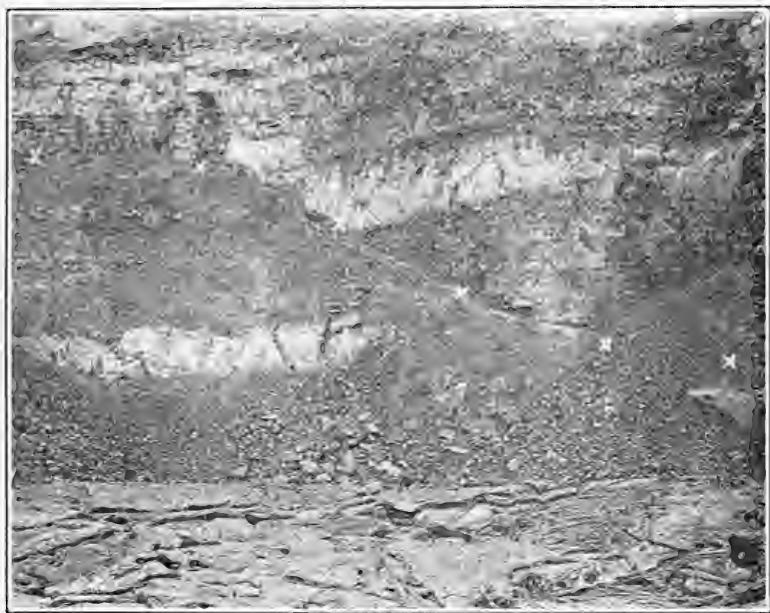


FIG. 2. The unconformity at the base of the cliffs at Uwekahuna (marked by crosses). The unconformity is overlain by ash against which the thick flows on the right side of the picture end. The ash bed can be traced on an almost horizontal line for a mile to the right of this section.

southwest; in the Koa forest, 6 miles north. The ejectamenta consist of ash, thread-lace scoria,* bombs, and fragments of rock and ordinary scoria of various sizes.

* Thread-lace scoria is a variety of basaltic pumice first described by Dana, in which the vesicles comprise 98 to 99 per cent of the mass, their walls being sieve-like or similar to thread-lace in texture. See this Journal (3), xviii, p. 134, 1879; Characteristics of Volcanoes, New York, 1891.

The age of the ejectamenta is very difficult to determine, even with reference to the very recent geological history of Kilauea, on account of the very meager descriptions of the early visitors. In 1823 Ellis saw "large stones and volcanic rocks" of the 1789 eruption on the floor of the sink now covered with lava.* The only material which has been ejected from Kilauea over the surrounding region since the eruption of 1789 is Pele's hair, which is frequently seen in large quantities on the Kau desert. The largest part of the ash must be of pre-historic age because it is overlain by the pre-historic Keamoku flow from Mauna Loa, is greatly altered in places where the steam-vents of past ages have been active, and is faulted in the fissures and faults seen especially on the south side of the sink, as will be shown below.

The origin of the ash has been discussed by Dana, Hitchcock, J. S. Emerson, Perret, and others. A number of measurements made by the writer in 1915 may serve as a basis for the presentation of the subject in a more complete manner than before. Heretofore the entire surficial deposit has been considered as the material of the 1789 eruption. It is shown below that this is probably not the case, and that there have been at least two ash eruptions since the last flow of lava spilled over the edge of the original Kilauea crater on to the region surrounding the present sink.†

On the northeast side of Kilauea, from the Halfway House past Kilauea Iki as far as Keanakakoi, the sections show thread-lace scoria at the base overlain by yellow ash with a stratum of fragments of basalt, scoria, and coarse ash. On the southwest side, the basal thread-lace scoria is missing and in its place is found yellow ash, with occasional thin layers of black sand with many olivine crystals, and of thread-lace scoria, overlain by coarse ejectamenta. On the surface near the sink are many blocks and bombs of large size which have made depressions in the ground where they struck. A thin veneer of the thread-lace scoria is found on the edge of the Kau desert, but the greater part of this light material has blown away since 1825 when seen by Goodrich, and even since 1864, when Dr. W. T. Brigham made his first survey of Kilauea.

The basal thread-lace scoria northeast of Kilauea rests directly upon the pahoehoe flows and is overlain conformably by ash. The thickness of the thread-lace scoria at places where it can be measured is (see fig. 3): 6 feet at the edge of one of the fault-blocks just north of the place where the trail from the Volcano House to Halemaumau meets the floor of

* C. H. Hitchcock, *Hawaii and its Volcanoes*, Honolulu, 1911, p. 171.

† The writer is indebted to Professor T. A. Jaggar, Jr., for many suggestions in the field, and to Professor R. A. Daly for kindly criticism of the manuscript.

the sink; $1\frac{1}{2}$ feet at the Volcano House and at the Prisoners quarry on the Kau road; 1 foot near the Crater Hotel; $\frac{3}{4}$ foot in the Fern Forest on the northwest and on the Uwekahuna fault-blocks; one to two inches at the Koa Mill on the north; the Prisoners camp on the west, and the Keauhou Pali on the south. The partial sections at Byron's Ledge and at Waldron's Ledge and at Keanakakoi do not expose the basal thread-lace scoria. Two of the complete sections may be given (see fig. 4):

FIG. 4.



FIG. 4. The ash section on the highway at the Prisoners quarry, showing thin beds of pahoehoe overlain by over a foot of thread-lace scoria (under the hammer), $1\frac{1}{2}$ feet of brown ash, and 1 foot of moderately coarse ejectamenta.

Prisoners quarry
(quarry and main highway)

1	$-1\frac{1}{2}$ feet coarse ejectamenta
$\frac{3}{4}$	$-2\frac{1}{2}$ " fine brown ash
$\frac{3}{4}$	-1 foot thread-lace scoria
<hr/>	
$2\frac{1}{2}$	-5 feet.

Volcano House
(north end, road-cutting)

1	foot coarse material
$\frac{1}{2}$	" thread-lace scoria and ash
$1\frac{1}{4}$	feet yellow ash
1	foot thread-lace scoria and black ash
1	" thread-lace scoria
<hr/>	
$4\frac{3}{4}$	feet.

The center of dispersion of the thread-lace scoria is apparently a point within the Kilauea sink, southwest of the Volcano House. Kilauea Iki does not appear to be the source of the material, judging from the sections at the Crater Hotel and along the automobile road to the crater. The thread-lace scoria is replaced by ash with a small amount of black olivine sand west of Uwekahuna, and in the vicinity of Keanakakoi.

Overlying the thread-lace scoria on the northeast side of Kilauea and directly overlying the basalt flows on the south side is a deposit of ash which is continuous over the whole area, although it may not all have been ejected in the same eruption or from the same vent. The ash is quite uniformly dark yellow in color, and of fine grain, but layers of coarser material grow abundant near the main source, and thin bands of thread-lace scoria, ordinary scoria, and olivine-bearing sand, and occasionally Pele's hair appear on close examination. Large bombs are comparatively rare in this deposit. Some of the ash is composed of pisolites, showing that rain fell at the time the ash was blown out.

The distribution of the ash is shown in fig. 3. The maximum thickness exposed is 25 feet on the "Peninsula" south of Halemaumau and west of the automobile road. The deposit thins rapidly in all directions. It has a thickness of from 12 to 23 feet along the southwest and southeast sides of the sink as seen in the fault-scarps nearest Halemaumau; 6 to 9 feet on the edge of the monoclinical slope nearby, a mile southwest of the crater; 6 feet at the foot of the trail to the floor of the sink from the Volcano House; and 1 to 3 feet over the surrounding region as along the 1868 cracks on the west, Uwekahuna, the Volcano House, the first of the pit craters on the southeast.

The source of the material is not conclusively shown, but the great thickness at the "Peninsula" suggests that the principal eruption came from the vicinity of the present Halemaumau. There is no indication of a source at Keanakakoi, but the thickness of about 12 feet at Byron's and Waldron's ledges suggest a vent in this vicinity.

The ash is overlain by a deposit of coarse ejectamenta composed of fragments of basalt such as is seen in the modern flows, and in the large blocks which must have come from some distance underground; bombs; scoria; and a small amount of ash. The deposit resembles gravel and many of the blocks are rounded like stream pebbles, but the material was never rounded by water.

The relation of the ejectamenta to the ash is probably a disconformity because very local unconformities are seen in the "Peninsula" and on the Kau desert, both on the top of the monoclinical slope south of Halemaumau and farther southwest.

The distribution of the coarse material is very similar to that of the ash. The thickness is 10 feet on the "Peninsula," 9 feet or less on the top of the fault-blocks on the edge of the sink southwest of Halemauau; $5\frac{1}{2}$ feet on the monocline at the edge of the desert and in the automobile road near the "Peninsula"; 3 feet at Keanakakoi; 1 to 2 feet from this place around the north end of the crater to the Prisoners quarry; $\frac{1}{2}$ foot at Uwekahuna, the Fern Forest, Crater Hotel, the second of the pit crater, and the 1868 cracks one mile west

FIG. 5.

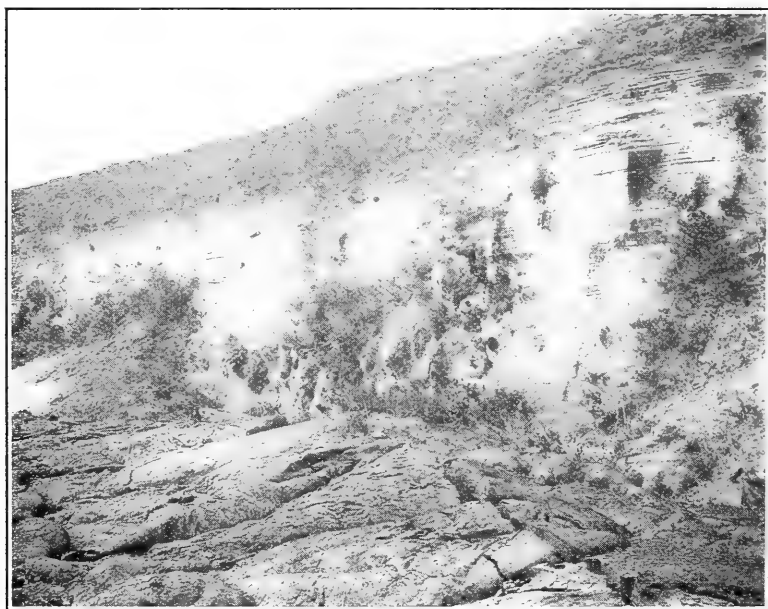


FIG. 5. The fault-scarp on the south side of the "Peninsula," showing 10 feet of coarse blocks and ash underlain by 22 feet of ash. The base of the ash is not seen at this place.

of the crater. Two complete sections may be given (see fig. 5):

The "Peninsula" (thickest section)		The monocline
surface gravel, bombs, etc.	1	foot surface gravel, thread-
10 feet coarse ejectamenta		lace scoria, Pele's hair
26 feet ash	$5\frac{1}{2}$	feet coarse ejectamenta
—	6	+ feet stratified ash
36 feet.	—	
	$11\frac{1}{2}$	+ feet.

The bed of coarse material varies in composition in the exposures around the crater, and it is coarsest southwest of Halemaumau. At the Volcano House and at the Prisoners quarry it is a gravel made up of fragments averaging an inch in length. At the Crater Hotel it is coarse ash with thread-lace scoria. Southwest of Halemaumau many of the fragments are from $\frac{1}{2}$ to 2 feet long.

On the southwest side of the sink the beds of coarse ejectamenta are overlain by thread-lace scoria whose greatest thick-

FIG. 6.

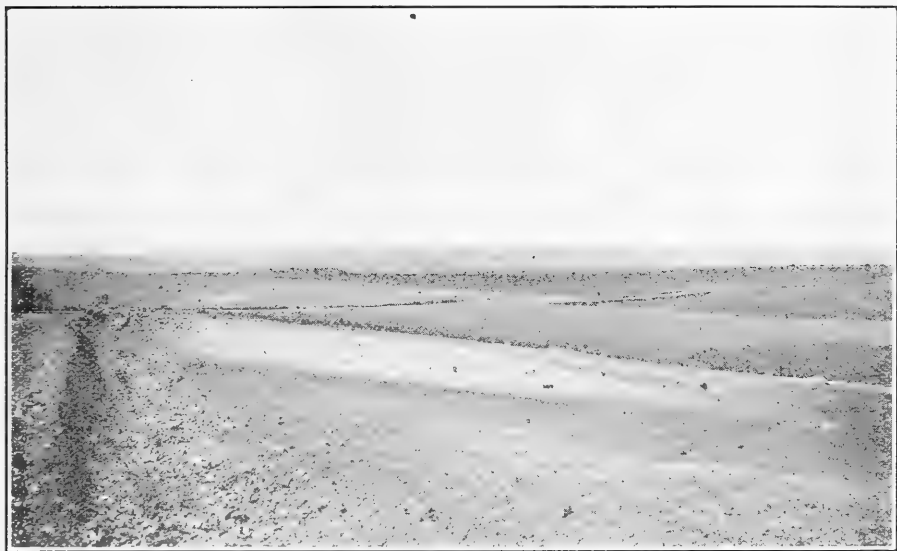


FIG 6. The gravelly plain south of Halemaumau showing a portion of the "Peninsula" at the extreme left and the monocline in the distance on the left. The boulders scattered over the plain were ejected in the 1789 eruption.

ness at the base of the monocline is little over one foot; by bombs; and by gravel a few inches in thickness. The thread-lace scoria has been blown by the wind so that what was apparently at first a wide-spread deposit is now confined to protected places. The bombs on the surface are uniformly of large size, from a foot in length to the largest measured, 8 feet long, 6 feet wide, 4 feet thick, composed of a banded rock from the throat of the volcano. On the "Peninsula" (fig. 6) these bombs are scattered over the plain at distances apart of from 10 to 100 feet. Toward Keanakakoi they become less frequent,

but the depressions made in the underlying deposit may be seen to greater advantage.* They do not extend on to the Kau desert beyond the monocline, but they are found on Uwekahuna with a diameter of 1 to 5 feet, and a quarter of a mile north of the edge of the pit one was found $4\frac{1}{2}$ feet long, 4 feet wide, and 3 feet high.

The youngest deposit of coarse material, "gravel," is difficult to separate from the thick deposits underneath. The top of it forms a hard crust over the gravelly plains of the desert area near Halemaumau. On the Kau desert a thin coating of this gravel covers the thread-lace scoria which is unconformable upon the older deposits.

Age of Ejectamenta.

The relative ages of the basal thread-lace scoria at the Volcano House, the ash overlying, the coarse material, and the 1789 ejectamenta remain to be considered. The first three deposits appear to belong to the same period of eruptive activity. They are all altered in places where steam has issued or is now issuing, they are all faulted alike, the local unconformities between them merely represent brief periods of repose, and they are all overlain by the Keamoku flow from Mauna Loa. It cannot be stated whether the three kinds of material represent three or many eruptions. Judging from the amount of ash ejected by one of the explosive type of volcanoes in a single eruption, as Sakurajima in 1914, all the older Kilauean ejectamenta might represent a single eruption lasting only a few days.

The surficial deposits of pumice, coarse ash, and bombs are separated from the others because they appear to be less altered, and less consolidated (except where rain-water has made a surface crust), and because they are found to rest unconformably on the other deposits, especially in places where the older beds are faulted and the younger material fills the fissures.

If the explosive material represents two eruptions or series of eruptions which took place at widely separated periods of time, as is argued above, was the first series before the formation of the present sink of Kilauea? On first thought this seems quite impossible, but an examination of the meager evidence may lend some support to this view.

The pre-historic deposits of ejectamenta are found on the fragments of the former summit of the volcano: the plains and the fault-blocks outside the present sink of Kilauea and

* These depressions have been photographed and described by Perret in this Journal (4), xxxv, 614, 1913.

outside the pit-craters Kilauea Iki and Keanakakoi; and the fault-blocks inside the sink which have not been buried by lava flows from the various Kilauean lakes of former times. The bedding planes of this explosive material are always *parallel to the upper surface of the lava-flows* upon which they rest, *no matter at what angle the fault-blocks are tilted.* Moreover, the faults which bound these blocks *truncate the partly consolidated ash beds* as well as the underlying lava flows, and the fault-scarps in the ash are almost perpendicular. If the faulting had taken place before the fall of the ash, the latter should have accumulated to a greater thickness on the lower side of a block tilted at an angle of 10° than on the upper side unless the ash fell when the trade winds were not blowing. Moreover, ash deposits 5 to 10 feet in thickness would have smoothed off the topography and filled small fissures; and even in the case of a fault such as bounds the "Peninsula" on the south, where there is a cliff of ash and ejectamenta 36 feet in thickness standing in an almost perpendicular wall, the ash could scarcely have fallen on the edge of a preëxisting cliff of truncated lava-flows and not have reached an angle of repose of about 30° . It may be argued that the faults referred to are not a part of the series of major collapses by which the sink has gradually been formed; but the same story is told in the blocks in front of the Volcano House, at Uwekahuna, at the monocline southwest of the crater, and in the rifts from Keanakakoi westward. Surely almost all of these faults were seen by Ellis in 1823 and they must have been formed before 1789 and during the collapse of the sink.

The formation of a sink the size of those at Kilauea and at the summit of Mauna Loa (Mokuaweoweo) must be a very slow break-down, judging from the changes which have gone on in these sinks from the time of the earliest records up to the present, by a mechanism not well understood. Even if the Kilauean sink took a very long time to form, and if the ash eruptions took place early in the process, these porous beds of ash would not show their great age because they do not retain water and therefore suffer extensive alteration only by steam.

One more question presents itself if the arguments above be accepted. From what source did the ash come: was the summit of Kilauea pitted by a few craters similar to those on Hualalai or Mauna Kea which have thrown out extensive ash deposits, or was there just a summit crater which suddenly became explosive? As there is no evidence that there ever were any ash cones of any magnitude on the summit of Kilauea, the first suggestion is unlikely. If there was a crater of the Halemaumau type on the summit, there may have been a situation somewhat resembling 1789, when, after a long

period of repose, explosions renewed the activity. No Kilauean lava flows are found on top of the summit ash, but that state of affairs can be accounted for both by the lack of any evidence concerning the possibility of flows near the crater and by the possibility that the sink was in process of formation at the time of the eruption so that lava could no longer run over the edge.

Formation of Thread-Lace Scoria.

The origin of the thread-lace scoria is involved in what precedes as, if it were understood, conditions in the past could be interpreted with greater certainty. It has recently been asserted that "all the material observed by the writer (Perret) lay upon the pahoehoe lava in a continuous stratum, indicating formation *in situ* and therefore not to be included under the head of ejectamenta."^{*} A review of the field evidence and of the literature leads the present writer to a different conclusion.

In the first place, the thread-lace scoria is found in a continuous stratum, so far as can be traced, from the Keamoku flow on the road to Kau to the Crater Hotel and probably farther along the road to Keanakakōi—a proven distance of 5 miles. The underlying pahoehoe flows at the places observed are only a foot or two in thickness and no single flow coming from the original summit of Kilauea ever poured over such an arc. Also, as shown above, there is an abundance of thread-lace scoria around Kilauea not overlying pahoehoe.

An examination of the literature shows that the thread-lace scoria was formed in the Mauna Loa outbreaks of 1852, 1858, and 1868. In 1852 Rev. Titus Coan visited the source of the flow of that year and found the pumice to be 5 to 10 feet thick in the vicinity of the cone from which the lava had issued, and to extend for a distance of 10 miles from the cone.[†] The source of the 1859 flow was visited during the eruption by W. L. Green, who writes: "At the lower side of the crater . . . we observed some vitrified breakers. The molten glass-foam had run over the lip of the crater in great waves and now stood on the gentle slope below like petrified combers on the seashore. The material of the waves seemed to be identical in composition and color with the usual Hawaiian pumice or glass foam, and the semi-transparent glaze covered the whole outer surface."[‡] J. M. Alexander reported the thread-lace scoria and Pele's hair from the same eruption when he ascended Mauna Loa in 1885.[§] In 1868 H. M. Whitney visited the

^{*} F. A. Perret, op. cit., p. 617.

[†] The original references will be found in W. T. Brigham's *The Volcanoes of Kilauea and Mauna Loa*, pp. 67-8.

[‡] *Idem*, p. 79.

[§] *Idem*, p. 160.

source of the Kahuku flow and reported that the ground was covered for a distance of 10 miles from the crater with basaltic pumice stone.* Dr. William Hillebrand visited the same locality a few days later and also reported the pumice.† In 1880 Dr. W. T. Brigham ascended Mauna Loa and reported that the summit plain for acres was covered with thread-lace scoria similar to that at Kilauea, which he describes as “froth of the burning lake.”‡ Thread-lace scoria has probably not been formed in any of the eruptions since 1868.

From the above it will be seen that the thread-lace scoria may be formed during the eruption of lava from the main crater from which the lava issues, and that it may be blown over great distances. Also, judging from the description by Green, the thread-lace scoria represents the glassy, gaseous froth of the lava.

Other Ash Deposits.

On the island of Hawaii deposits of ash are also found in small quantities on the Kohala Mountains, on Hualalai; and in large quantities on the slopes of Mauna Kea and in the region of the Mohokea “crater,” northwest of Pahala, stretching from Kaalualu to Kapapala. In the first two localities the ash is confined to the vicinity of the summit and lateral cones and cone-craters, and therefore needs no further description.

The closing stages of activity of Mauna Kea were marked by the development of large ash cones which completely bury the bed-rock summit of the mountain, thereby making it 200 feet higher than Mauna Loa. The ash deposits envelop the mountain, where they have not been removed by subsequent erosion, and on the ash-covered slopes near the sea on the eastern side are the sugar-cane plantations of Hamakua and of North and South Hilo. At Hilo the ash disappears beneath the younger lava flows from Mauna Loa. A short distance north of the lower iron bridge at Hilo over 5 feet of ash is exposed; near Papaikou 20 feet of ash is seen overlying aa lava; at the shore at Pepeekeo 40 feet of ash overlies the basalt; at Paauilo less than a foot of ash is seen near the railroad; at Weha, near Paauhau, a three-inch vertical fissure in aa has been filled with ash which is about 4 feet thick on the surface; at Honokaa the ash is 3 to 5 feet thick; on the Waimea plateau at an elevation of about 2700 feet the ash is 2 to 3 feet thick. On the west side of Mauna Kea the ash is also seen, and at Keamuku gulch it is 3 feet thick. South of this point, however, it is concealed by younger flows from Mauna Loa and Hualalai.

* Idem, p. 105.

† Idem, p. 111.

‡ Idem, pp. 20, 144, 92.

The maximum thickness—over 40 feet—at the base of the mountain appears to be on the northeast side from Pepeekeo to Maulua Bay.

The ash deposits near the Mohokea depression have already been described by Hitchcock* and by Emerson.† Their source is ascribed to Mokuaweoweo by the former, because of certain other deposits of ash at Humuula, on the plateau between Mauna Loa and Mauna Kea (this ash may have come from the latter mountain), and to Mohokea by the latter writer. The latter view is here favored because the deposit is confined to the Mohokea district, and is not reported on the upper slopes of Mauna Loa.

The Mohokea ash extends from the vicinity of the Kapapala ranch, west of Kilauea, past the Mohokea shield-shaped depression and Kaalualu, to the southernmost point of the island, Ka Lae, a total distance of 29 miles. The direction of the trade winds is from Mohokea toward Ka Lae, which places are 21 miles apart. There is a surface deposit of ash, covered by later flows from Puu Enuhe to Hilea on the south side of the Mohokea depression, and from the cliff, which extends south-eastward from Waiohinu, nearly to Kaalualu; and there are also older deposits interbedded with lava flows, as seen in exposures in the Mohokea district, especially near Kaumaikohu, at Honuapo, and near Kaalualu.

The thickest section observed occurs in a stream bed near Kaumaikohu. The gulch was followed downstream for about half a mile only and it is probable that other flows and ash beds are exposed below this point. The section is as follows:

	Top, an erosion surface
	4 ± feet ash
5-20	" pahoehoe
10 +	" ash
4	" pahoehoe
15 ±	" ash, containing blocks of vesicular basalt 1 foot in diameter.
6	" ash and ejectamenta
6	" ash
10	" pahoehoe
10	" ash (black)
?	" pahoehoe
	Base not seen.

At Honuapo a section is exposed at the sea in a cliff which has probably been formed by a landslide in 1868 (or 1887). Northwest of the house at Kaalualu in a small dry gulch

* Op. cit., pp. 154-158. † Op. cit.

another section is seen. These sections are given for comparison :

Kaalualu	Honuapo
Top: possibly another flow	Top: an erosion surface
5 -10 feet ash	3-15 feet ash
2½- 3 " lava	10-15 " lava
7 -10 " ash	10 ± " ash
? lava	12 ± " lava
	10 ± " ash, base not seen.

At Pahala and at Naelehu the cane-fields are situated on a yellow ash bed over 10 feet in thickness, but south of Pahala in the grazing land from the highway to the recent flows from Kilauea the ash is very thin. It is owing to the fertility of the ash that cane can be raised with a very small supply of water.

Although a thorough reconnaissance of the entire Mohokea territory is impossible on account of the impenetrable tropical jungles in which one walks on decayed vegetable matter and never sees fresh rock, it is thought that the interbedded ash deposits and lava flows came from some source now concealed in the Mohokea region. It is not possible to discuss here the possibility of the former existence of a crater in the Mohokea area of down-faulted blocks, but the ash beds might be used as evidence favoring the crater theory.

Summary.

It has been shown that the ash deposits on Hawaii are found on the flanks of all the volcanoes, but especially on Mauna Kea where the closing stages of activity were marked by enormous ash-eruptions ; on the southwest slope of Mauna Loa ; near the crater-like depression Mohokea ; and on the summit of Kilauea. In the first instance the ash beds now exposed appear to be almost entirely surficial ; at Mohoka it is interbedded with the lava ; at Kilauea it occurs interbedded with the flows and on the outer rim of the sink.

The visible Kilauean ejectamenta have been described as principally surficial. The interbedded deposits are exposed in only a few places in the walls of the sink, but they suggest many catastrophic periods in the older history of the volcano. The ejectamenta on top of the walls of the sink cover the surrounding region and have a maximum thickness of 36 feet near the present crater Halemaumau. These deposits represent two eruptive periods : the older, of pre-historic age, comprising most of the deposit and consisting of basal thread-lace scoria at the northeast part of the sink, overlain by ash which surrounds

the sink, and by coarse ejectamenta over the ash; the younger, belonging to the 1789 eruption, consisting of thread-lace scoria, ash and bombs. The age of the older deposit is uncertain, but evidence is given favoring the view that it may be older than the present sink.

Thread-lace scoria, a variety of basaltic pumice, is found to be a peculiar kind of gaseous lava-froth which has been blown out of craters and not formed *in situ* on the surface of pahoehoe flows. It appears to represent the extreme phase of gaseous pumice where the vesicles are separated by only slender threads instead of by walls.

Troy, N. Y.,
December 9, 1915.

ART. XIII.—*Succinic Acid as a Standard*; by C. A. PETERS
and V. SAUCHELLI.

Phelps and Hubbard* have stated that succinic acid may be used as a standard for volumetric work against ammonium hydroxid with cochineal as an indicator. The statement of Phelps being contrary to the experience of one of the authors, the standard of ammonia against succinic acid under conditions as outlined by Phelps and Hubbard was determined again, and compared with that obtained electro-titrametrically according to van Suchtelen and Itano.† We were unable to duplicate the work of Phelps and Hubbard relating to the comparison of ammonia and succinic acid.

Preparation of Succinic Acid.—The succinic acid was prepared according to one of the methods given by Phelps and Hubbard, it being dissolved in boiling distilled water and then allowed to crystallize. The first crystals were washed with water and recrystallized. They were then dried on filter paper in the air, and kept in a desiccator over sulphuric acid.

The melting point of the purified succinic acid determined in an open capillary tube was 183.0° C. The thermometer used was calibrated and corrected for steam exposure.

Apparatus.

Conductivity Cup.—As the ordinary Ostwald type of cell does not allow convenient thorough mixing of solutions, the

* This Journal (4), xxii, 211, 1907.

† Jour. Amer. Chem. Soc., xxxvi, 1793, 1914.

type described by Robbins* in the article following was used. *Temperature Regulator.*—A conductivity cell was placed in a 12-liter heavy glass tank. The temperature, so controlled, was 13°. *Bridge.*—A 100^{cm} wire calibrated by the method of Strouhal and Barus.

Standards.

Succinic Acid.—This was made in strengths as required by weighing out the desired portions. A mold invariably developed in the succinic acid solution. This necessitated working with fresh solution at each trial. However, several titrametric trials made on a solution of acid containing mold showed that the solution did not undergo change in normality in a few days or, if it did, the change was so small as to be undetectable with the methods employed. *Ammonia.*—The ammonia either was compared with hydrochloric acid which was gravimetrically standardized as silver chloride, or was compared with sulphuric acid which was standardized with carbonate of soda made from the acid carbonate by careful heating to 300°.

Procedure.

Electro-titrametrically.—The tip of a burette being inserted between the electrodes, a measured volume of ammonia water was drawn off. Then a measured quantity of succinic acid solution was drawn from a similar burette and the solutions were thoroughly mixed. This was accomplished by sucking the contents of B up into M by means of mouth aspiration applied to a soda-lime tube attached at S.† Three or four applications of suction were sufficient to mix the liquids as evinced by the lack of change in the bridge readings. The bridge was then balanced. Further portions of the succinic acid solution being added, the process was repeated until several points each side of the neutral point were obtained.

Results.

The results are collected in Table I which follows, and also are shown in the accompanying graphs.

These figures show that when 10^{cc} of ammonia were introduced into the cup and successive portions of succinic acid, 9 grams to the liter, N. 0.1525, were added, the results of the duplicate determinations, given in I and II of Table I, indicate that 8.13^{cc} of succinic acid were required to neutralize

* This Journal (4), xli, p. 249, 1916.

† Ibid., p. 250.

FIG. 1.

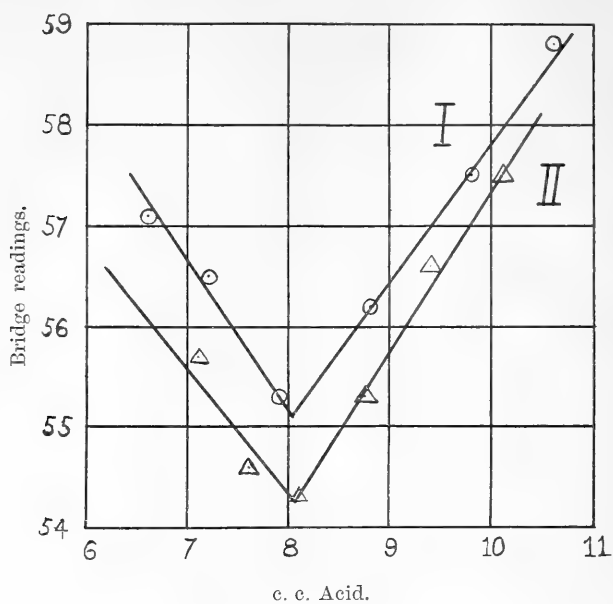
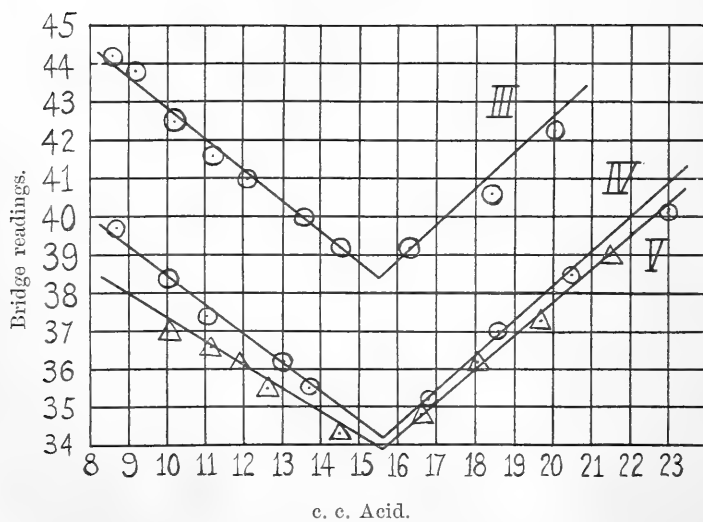


FIG. 2.



the ammonia. This gave the ammonia a normality of 0.1240. The figure obtained by the titer against hydrochloric acid was N. 0.1224. When the succinic acid was titrated against ammo-

TABLE I.

Electro-titrametrically 10 ^{cc} ammonia				By Titration	
Succinic Acid Solution cc.	Bridge Readings	Succinic Acid Solution cc.	Bridge Readings	Ammonia cc.	Succinic Acid Solution cc.
I		II		I & II	
6.6	57.1	7.1	55.7	40.20	44.7
7.2	56.5	7.6	54.6	40.00	45.0
7.9	55.3	8.09	54.3	40.00	41.3
8.8	56.2	8.75	55.3	40.00	40.7
9.8	57.5	9.4	56.6	40.40	41.0
10.62	58.8	10.1	57.5		
III		IV		200.60	212.7
8.6	44.2	8.75	39.7	III, IV & V	
9.2	43.8	10.00	38.4	30.0	61.2
10.2	42.5	11.05	37.4	30.0	50.0
11.2	41.6	13.05	36.2		
12.1	41.0	13.7	35.5	60.0	111.2
13.55	40.0	15.6	34.2		
14.55	39.2	16.8	35.2		
16.3	39.2	18.6	37.0		
18.4	40.6	20.5	38.5		
20.05	42.5	23.0	40.5		
V					
10.05	37.0				
11.15	36.6				
11.90	36.6				
12.6	35.5				
13.6	35.3				
14.5	34.3				
16.6	34.8				
18.05	36.2				
19.7	37.3				
21.5	39.0				

nia using cochineal as described by Phelps and Hubbard, in 5 titrations 200.6^{cc} of ammonia were used against 212.7^{cc} of succinic acid, the normality of ammonia was 0.1313. The individual variations in the amounts of succinic acid used were as high as 12 per cent, and the end points always were uncertain.

In III, IV and V of Table I are shown the results obtained by adding 10^{cc} ammonia of normality 0.524 to succinic acid, 4.0046 grams per liter, normality 0.3392. The breaks in the graphs show the neutral points to be at the addition of 15.6^{cc} of acid, which would give the ammonia a normality of 0.525. The normality obtained by comparison of sulphuric acid was 0.5292. To get the normality of the ammonia solution by use of cochineal two determinations were made using, in all, 60^{cc} of ammonia against 111.2^{cc} of succinic acid, the individual determinations varying as much as 20 per cent. These gave the normality of the ammonia as 0.377. The results are summarized in Table II which follows:

TABLE II.

				Normality of ammonia water calculated as designated:		
Graphs	Ammonia Sol. used cc.	Succinic Acid Sol. used cc.	Normality Succinic Acid cc.	Electro- titramet. Succinic Acid	Mineral Acid	Phelps and Hubbard
I & II	10	8.13 aver.	0.1525	0.1240	0.1224	0.131
III, IV, & V	10	15.6 aver.	0.33922	0.525	0.5292	0.377

The figures show that the results obtained by standardizing ammonia water against mineral acid in presence of methyl orange agree quite closely with the standards obtained by the use of succinic acid electro-titrametrically, but no standard of value could be obtained by the action of succinic acid on ammonia in the presence of cochineal as described by Phelps and Hubbard.

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ART. XIV.—*Conductivity Cell for Electro-titration*; by
HAROLD E. ROBBINS.

THE type of cell shown in the accompanying sketch (p. 250) was devised with the following requirements in view: (*a*) protected electrodes; (*b*) unobstructed access to electrolyte with burette; (*c*) adequate mixing of the electrolyte without the complications of mechanical stirrers; (*d*) sufficient rigidity to permit of frequent cleaning and handling, combined with economy of materials.

It will be seen that these requirements are met when each item is considered in detail. (*a*) The electrode holder, C, has an outer shell which projects beyond electrodes and protects them from accidental injury, while leaving them readily accessible. The platinum foil electrodes are themselves curved for rigidity and sealed into the glass mercury tubes with No. 20 platinum wire. The mercury tubes are sealed at the top to the wall of the surrounding glass protector.

(*b*) The space between the mercury tubes and the shell is sufficient to permit the ready introduction of reagents from burettes.

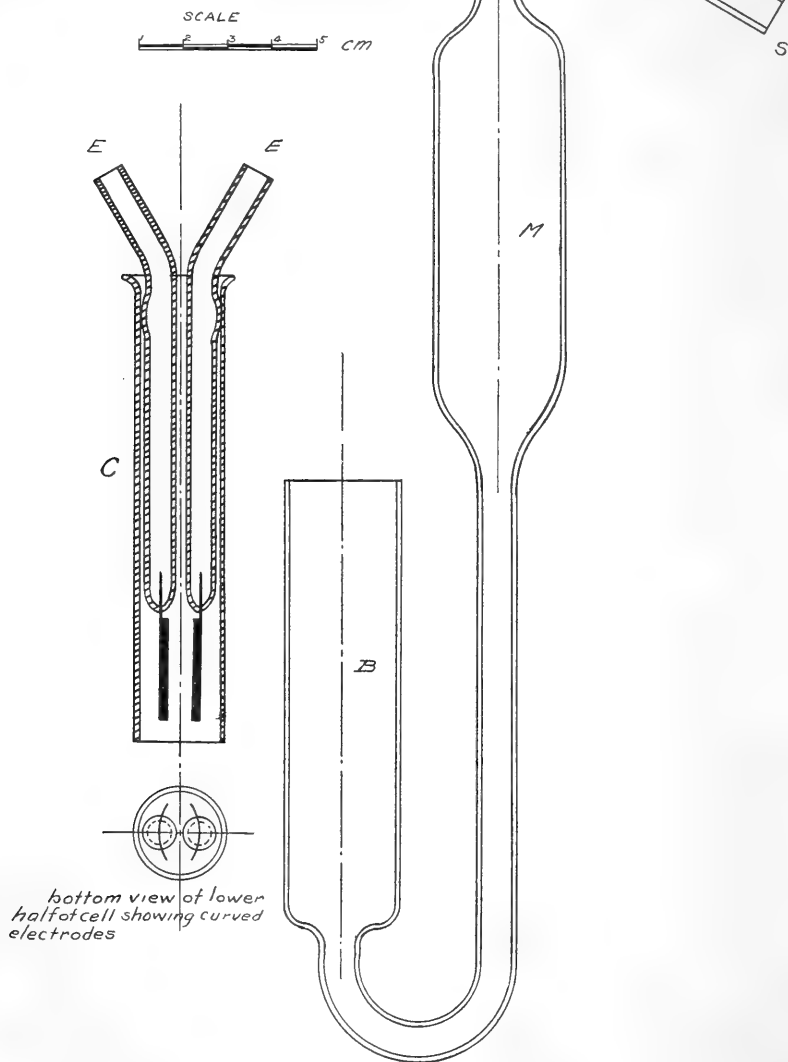
(*c*) The mixing is performed as follows: The electrode holder, C, fits loosely into the cell jar, B, the base of the holder resting on base of B. Attached to S is a soda-lime tube and mouth-piece. When the cell is placed in thermostat, and some reagent is added to solution in the cell, suction on mouth-piece causes the electrolyte to rise into M. The electrolyte is then allowed to run into B and the operation is repeated. Repeated tests indicated that from two to four mixings are sufficient to enable operator to obtain constant readings on the bridge.

(*d*) Stock material is used throughout in the construction and the cell is amply strong.

In a modified form to be described at a later date, it is proposed to describe a more compact type with spherical bulbs of larger capacity for B and M, also a slightly modified form for holder C.

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CONDUCTIVITY CELL
FOR ELECTRO-TITRIMETRIC WORK



ART. XV.—*Evidence of the Ligamentum Teres in Nebraska Proboscidea*; by ERWIN H. BARBOUR.

INCIDENTAL reference was made in this Journal* to the round ligament of Nebraska proboscideans as evidenced by specimens in the collections of the Nebraska State Museum. However the subject seems to be worthy of more than passing mention. Comparison of acetabula of our various mastodons and mammoths lead to the conclusion that absence of the round ligament is not properly a character of the Proboscidea. From evidence at hand it appears that the round ligament may have been present in all of our Proboscidea. In some it seems to have been large and functional. This is true particularly in the case of the longirostral mastodons of the Pliocene of Northern Nebraska, and to a degree in the case of some of the brevirostral forms from the Pleistocene. Femur heads of the former show deep and unmistakable ligamentous scars, while those of the latter show little if any.

In the case of brevirostral mastodons from our Pleistocene, reduction of the round ligament is evident. Still even here the fossæ are long, broad, and relatively shallow though occasionally deep. The femur heads of some mastodons show slight scars, and roughened areas for attachment, although the bulk of them are smooth as in *Mastodon americanus*. As for mammoths the fossæ are long, broad, and in certain instances, surprisingly deep. In one case, at least, the fossa is not only relatively but actually broader, longer, and deeper than in the early longirostral forms. However the femur heads of mammoths seem to be as free from scars as those of modern elephants. Obliteration of the acetabular fossa was a slow process judging by the specimens at hand, which range from the Pliocene and Pleistocene to the present. In none is the fossa filled by osseous growth as in the modern elephant. All this seems to be morphological rather than coincidental. Nebraska seems to be singularly rich in proboscidean remains. Four mammoths and at least twice as many mastodons have already been described and many more are destined to be added to the list.

The "tetrabelodon beds" of Nebraska extend along the northern tier of counties from Knox through Sioux, a distance of some 300 miles.

In the case of the Boyd County Tetrabelodon the acetabular fossa is deep and large. This is a new and undescribed Tetra-

* Barbour, Erwin H., A New Longirostral Mastodon, *Tetrabelodon lulli*, this Journal, vol. xxxix, p. 87, Jan., 1915.

FIG. 1.



FIG. 1. Acetabulum of *Tetrabelodon willistoni* showing a narrow cotyloid notch, and the fossa broadening and deepening toward the center. $\times 1/10$.

FIG. 2.

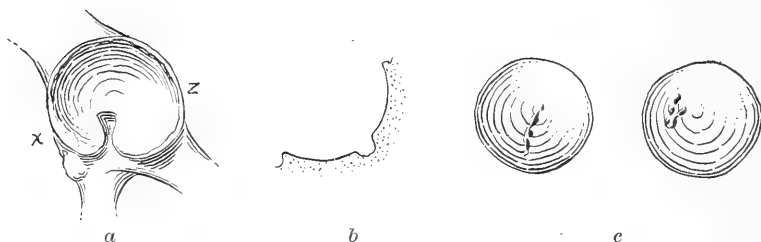


FIG. 2. *a*, acetabulum of *Tetrabelodon lulli* showing a narrow fossa of medium depth, with a deep central pit. Note the tuberosity below *x* for the attachment of the pectineus muscle. Compare with fig. 6. *b*, section of acetabulum along the line *xz*. *c*, femur heads showing pits and scars.

FIG. 3.

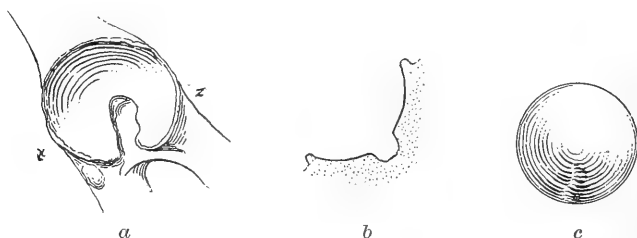


FIG. 3. *a*, acetabulum of *Eubelodon morrilli* showing a broad, deep, pitted fossa. Pectineus protuberance below *x*. *b*, section of acetabulum through the line *xz*. *c*, head of the femur showing scar. $\times 1/10$.

FIG. 4.



FIG. 4. *a*, acetabulum of *Mastodon americanus* showing a well defined though shallow fossa. *b*, section through the line *xz*. *c*, head of the femur without scar. $\times 1/10$.

FIG. 5.



FIG. 5. *a*, acetabulum of *Elephas imperator* showing well-developed fossa one and one fourth inches deep. *b*, section along the line *xz*. *c*, head of femur without scar. $\times 1/10$.

FIG. 6.



FIG. 6. *a*, acetabulum of *Elephas indicus* showing obliteration of the acetabular fossa. The pectineus pit is on the pubis below *x*. Compare with figs. 2 and 3. *b*, section along the line *xz*. *c*, head of femur without scar. $\times 1/1$.

belodon collected the past season by the writer. It shows more striking peculiarities and is altogether more unique than any longirostral mastodon in our collections. Fortunately the skull mandible and practically the complete skeleton were procured and will be the subject of a special paper. A little farther west in Brown County the writer secured two longirostral mastodons recently described as *Tetrabelodon willis-toni*, from a lower horizon, and *Eubelodon morrilli*, from a higher. The acetabula referred to *Tetrabelodon willis-toni* are small, but half as large as mammoths. The cotyloid notch is narrow and shallow, but the fossa is deep and expanded toward the center of the cup, where it is rough and pitted. In *Eubelodon morrilli* a perfect pelvis was found with the skull and certain skeletal parts, so the identity seems certain. The acetabula measure $6\frac{1}{2}$ in. (165^{mm}) across. The fossæ are 3 in. (76^{mm}) long by $1\frac{1}{2}$ in. (38^{mm}) broad. They deepen centrally to a full inch (25^{mm}) and are very rough and pitted for ligamentous attachment. The corresponding femur heads have pronounced scars. In this case the existence of the round ligament seems reasonably certain. It was presumably large and functional. Still further west in Cherry County (in the Snake River beds, Pliocene) was found the unique specimen, *Tetrabelodon lulli*. Its acetabula are $6\frac{1}{2}$ in. (165^{mm}) in diameter. The notches are narrow, and moderately shallow, but toward the center of the cup the fossæ broaden, deepen to 1 in., and are roughly pitted. The corresponding femur heads are scarred and pitted. From the Pleistocene of the state come a number of acetabula and femur heads of the later mastodons and mammoths. The acetabula of *Mastodon americanus* average about 7 in. (178^{mm}) in diameter. All show long broad, relatively shallow but well-developed fossæ. Corresponding femur heads are smooth as in mammoths and modern elephants. Our mammoths have large acetabula measuring 8 to $8\frac{1}{2}$ in. (203 to 216^{mm}) across. The femur heads are without scars. The fossæ are 4 in. (101^{mm}) long, 2 in. (50^{mm}) broad, and $1\frac{1}{4}$ in. (32^{mm}) deep. The round ligament was undoubtedly reduced but not suppressed. In living elephants the acetabular fossæ are filled flush with the surface by osseous growth and absence of the ligamentum teres is a character. A comparison of a number of specimens seems to justify belief in the existence of the round ligament, especially in our tetrabelodons.

The accompanying figures are drawn from specimens in the collections of Hon. Charles H. Morrill, in the Nebraska State Museum.

The University of Nebraska,
September 20, 1915.

ART. XVI.—*Fossiliferous Miocene Boulders from Block Island, R. I.*; by HERVEY W. SHIMER.

A FOSSILIFEROUS boulder of rather soft, dark gray argillaceous limestone was found in November last upon the beach at Balls Point, the northeast shore of Block Island, by T. A. Watson and W. O. Crosby. This rounded boulder, with a weight of six pounds, is very full of fossils and from it were identified twelve species. The most abundant form was *Ostrea*; somewhat less numerous were *Cliona*, *Arca*, *Isocardia* and *Corbula*. As is seen from the list below, the fossils indicate a Lower Miocene age, all of the species occurring in the lowest horizon in Maryland, the Calvert, and some of them confined to it. In the list, C = very common, c = common, r = rare, R = very rare, in occurrence in the boulder.

Cliona sp. C. Many sponge borings into *Ostrea*. They are about .3^{mm} in diameter and average 1^{mm} apart.

Leda liciata (Conrad). c.

Corbula cuneata Say. c.

Tellina sp. R. Shell when entire was about 30^{mm} long; it is 15^{mm} high. Break anterior, within 5^{mm} of the end of shell. Area well marked. Surface with concentric growth lines.

Phacoides cf. *anodonta* Say. R.

Isocardia cf. *mazlea* Glenn. C. Somewhat less than one-half the size of the Maryland specimens.

Arca cf. *marylandica* Conrad. C. The numerous radial striae are not strongly granulated. Ligament area with transverse lines, and from the beak, diverging at angle of 120°, extends a furrow, both anteriorly and posteriorly, to the teeth. These are all left valves. About the same number of right valves of an *Arca* are present, but with a decidedly different sculpture. The radial striae are, anteriorly, similar in number but lower and less angular, and upon the posterior slope they disappear entirely. The area was not seen. These two arcoid forms so similar in form and number, with each confined to one kind of valve, strongly suggest these to be opposite valves of the same species. It is evidently an undescribed form, but I hesitate to make a new species from a boulder of unknown parentage.

Ostrea cf. *sellæformis thomasi* (Conrad). C. Large specimens about 50^{mm} long. The lower valve has a short punctate impressed line near the hinge line; in the upper valve this is replaced by a transversely denticulate margin confined likewise to the neighborhood of the hinge.

Turritella plebeia Say. R.

Vermetus virginicus (Conrad). C. Diameter of tubes 2.5^{mm}. Surface with only concentric wrinkles and growth lines.

Cerithium sp. r.

Cerithiopsis cf. *calvertensis* Martin. R.

The fauna of this Block Island boulder is most closely related to the Lower Miocene, the Calvert, of Maryland. Compared with other Tertiary occurrences in this part of New England the fauna is unique. It is entirely different from the fauna of the Eocene boulders found first by Warren Upham and later by Professor Crosby and others upon the beach and in the glacial till of the bluff at Truro, Massachusetts. It is specifically distinct from the Eocene fauna found by Hollick and figured by T. C. Brown* from the ironstone concretions of Chappaquiddick Island, Martha's Vineyard. It contains nothing in common with the Upper Miocene fauna of Gay Head, Martha's Vineyard, as listed by Dall,† nor with the Pliocene forms found by Woodworth in the same region.‡ Likewise it is entirely distinct, both lithologically and faunally, from the Miocene phosphatic pebbles found by Woodworth on the south shore of Block Island, and subsequently ascertained to have been "derived from the wreck of a vessel loaded with phosphate rock from the east bank of the Ashley River, S. C."§ It also has nothing in common with the small fauna from near Southampton, Long Island, identified by Gratacap as Pliocene.||

Considering the possibility of the transportation of boulders as ballast, etc. from place to place, it may be well to hesitate for further light, such as finding similar boulders in the till, before assigning this boulder definitely to a parent ledge in New England.

Another boulder, slightly smaller than the preceding, was found by Mr. John E. Tourgee upon the beach at the extreme northern end of Block Island. This hard sandstone boulder is also highly fossiliferous but the fossils are usually merely external and internal molds and difficult of identification. The most abundant form is identified as *Pecten* cf. *jeffersonius edgecombensis* (Conrad). It is one-half as large as that variety. Another abundant form is probably the same as the oyster in the other boulder, *Ostrea* cf. *sellæformis thomasi* (Conrad).

Massachusetts Institute of Technology.

* This Journal (4), xx, 229.

† Ibid. (3), xlviii, 297.

‡ Loc. cit., p. 229.

§ This Journal (3), xlviii, 300.

|| Nautilus, xxviii, p. 85.

ART. XVII.—*The Summation of Chemical Analyses of Igneous Rocks*; by H. H. ROBINSON.

THEORETICALLY the summation of a complete chemical analysis should be 100 per cent; actually it rarely is that. Although an analyst may take every precaution to ensure a strictly accurate result, most of his summations will be either higher or lower than the true one. Are these departures from the mean value distributed in any definite and orderly manner? It is the purpose of this paper to discuss this question in general as well as in individual cases, first touching briefly on some of the analytical errors that may affect such a distribution, and also to show how the probable errors of an analyst's summations may be used as a guide to the quality of the analytical work.

The study is based on the analyses of the Washington and Washington-Roth tables,* as well as on more recent analyses. Their number is 3,391. The only analyses omitted are: (1) those whose summation has been recalculated to 100 per cent, or by estimation of some constituent is equal to 100 per cent, and (2) those whose summation is distinctly low through the non-determination of some constituent. The statistical data are given in Table I. The summations were tabulated, and are here given, on the basis of a 0.05 per cent unit in order to lessen work.

An inspection of the table shows that there are few analyses with low summation, but that the number increases in a striking manner from about 99 per cent to a maximum at 100.15–100.19 per cent. Likewise there is a marked decrease in the number of analyses from the maximum to about 101.50 per cent and then a gradual decrease to the highest summations. The different summations are thus distributed with considerable regularity either side of the maximum. What is the probable character of this distribution?

As a matter of pure chance it would seem probable that the high and low summations should be evenly distributed either side of the maximum, provided no unusual factors affect the summation of the analyses. The fitted distribution or probability curve should be symmetrical with respect to the vertical axis passing through the maximum. It is necessary, therefore, to examine the factors involved before a conclusion can be reached as to the most probable character of the distribution.

It appears most likely that the errors due to the methods used in the determination of the individual constituents of a silicate analysis tend to balance one another, so that, given

* Washington, H. S., *Chemical Analyses of Igneous Rocks*, Prof. Paper, U. S. G. S., Nos. 14 and 28, 1903 and 1904.

TABLE I.

The number of analyses from 97·00% to 103·50% for groups of summations differing by 0·05 per cent.

Summations.	97	98	99	100	101	102	103
·00-·04	1	2	19	139	26	3	--
·05-·09	--	--	15	143	29	4	--
·10-·14	1	1	29	144	10	--	--
·15-·19	--	4	22	151	20	--	--
·20-·24	--	1	30	128	12	3	--
·25-·29	1	1	29	131	18	--	--
·30-·34	--	4	34	133	12	2	1
·35-·39	--	1	36	114	17	2	--
·40-·44	--	2	49	83	8	1	1
·45-·49	1	1	42	88	9	2	1
·50-·54	--	4	49	90	2	1	--
·55-·59	--	3	47	77	7	3	--
·60-·64	1	4	71	69	5	1	--
·64-·69	1	3	82	69	3	--	--
·70-·74	1	4	95	67	3	1	--
·75-·79	--	6	96	59	6	--	--
·80-·84	--	5	116	48	3	1	--
·85-·89	1	2	119	43	2	--	--
·90-·94	2	4	142	36	1	--	--
·95-·99	--	8	131	34	2	--	--
Totals	10	60	1253	1846	195	24	3
Grand total	3391						

sufficient analyses, their effect on the general average is equal to zero. Washington* gives figures for the allowable variation in duplicate determinations of the various oxides, all of which may be either plus or minus, in which case they would tend, of course, to balance one another purely as a matter of chance. Dittrich,† on the basis of special determinations, decided that errors of a certain size and direction were to be expected for six of the common rock elements expressed as oxides. However, part of the analytic work was not done by Dittrich and was poor, and as a whole it hardly warranted quantitative conclusions. The qualitative statement of the results is that a minus error is to be expected for alumina, a plus error for ferric iron, and a plus or minus error for lime,

* Washington, H. S., *Chemical Analysis of Rocks*, p. 24, 1904.

† Dittrich, M., *Ueber Genauigkeit von Gesteinanalysen*, *Neues Jahrb. f. Min. u. Geol.*, vol. ii, p. 69, 1903.

magnesia, potash, and soda. An examination of the best methods used in rock analysis, such as are given by Hillebrand,* shows that the probable character of the errors in the determination of individual oxides is as follows:

SiO ₂	—	MgO	+	H ₂ O	±
Al ₂ O ₃	—	CaO	±	TiO ₂	—
Fe ₂ O ₃	+	Na ₂ O	±	P ₂ O ₅	+
FeO	—	K ₂ O	±	MnO	+

On account of the customary practice of determining Al₂O₃ by difference, the errors for Fe₂O₃, TiO₂, and P₂O₅ have to be considered as a single error the value of which is plus. If, then, the errors as a whole are of about the same size, it is evident that they will tend to balance because the chances for plus and minus errors are equal.

The errors which result from analytic methods alone rarely neutralize one another in individual analyses. They do so only in an average based on a large number of analyses. The size of the unbalanced errors, however, can not well be large because present-day methods of silicate rock analysis are reasonably accurate. No doubt such errors were more pronounced in the older analytic work due to less accurate methods, less well developed technic, and to poorer reagents.

It may be concluded, then, that errors due to methods should bring about a slight dispersion of individual summations on either side of the general average and that this distribution should be symmetrical because there is an even chance for plus and minus errors.

There is not a complete balancing of all the errors affecting a summation. As is well known, analyses commonly add up to more rather than less than 100 per cent. For example, 61 per cent of all the analyses used in this study have summations above 100 per cent. The actual average summation for all the analyses is 100.13 per cent. There is thus a small constant plus error due not to unbalanced errors in methods but to different sources such as impurities derived from reagents or from glass and porcelain vessels and to dust. This error was slightly greater (0.2 per cent) in older analytic work and in the future it may well be smaller than at present. It seems hardly possible, however, that it will ever be entirely eliminated.

The conclusion that errors in methods tend to offset one another presumably holds only for analytic work of the better quality. In poor work there may be unbalanced errors. One such error is found in the determination of magnesia. To illustrate this analyses with more than 20 per cent of magnesia

* Hillebrand, W. F., *The Analysis of Silicate and Carbonate Rocks*, U. S. Geol. Survey Bull. 422, 1910.

and not over 10 per cent of water are used. The high percentage of water is unavoidable because the olivine-bearing rocks, which contain large amounts of this element, are particularly susceptible to alteration. The results are:

Quality of work	Number of anal.	Ave. summation
Superior	29	100.14
Inferior	10	100.60

The analyses in the superior group have the same average summation as the general average; presumably the common plus error in the determination of magnesia is sufficiently small to be counterbalanced. On the contrary, the inferior group has a high summation. It is 0.47 per cent above the general average, which is a significant amount and must largely represent the plus error in the determination of magnesia. In general it is no doubt true, except for the best work, that magnesia has been determined in excess of the real amount by the older analytic methods. Gooch and Austin* have shown the conditions which cause this error, as well as how it may be avoided. On the basis of their special determinations an error of 1 in 40 may be expected. The inferior analyses just given show a smaller average error than this, caused probably by counterbalancing errors in the determination of other constituents. It is possible, of course, that the plus error in the determination of MgO itself might raise the general average summation above 100 per cent. The average igneous rock of the earth's crust contains about 4 per cent of MgO and on the proportion of 1:40 the plus error would be 0.10 per cent. However, so large an average error is not allowable, because in many rocks MgO undoubtedly has been correctly determined. Yet with this qualification a small part of the constant plus error in the general average summation might well be due to this cause.

An unbalanced error might be expected in those analyses in which iron has been determined wholly as ferric or as ferrous oxide. Such a procedure should affect the summation provided the oxide not determined is present in any considerable amount. Theoretically, if an analysis shows a total of 15 per cent of ferric oxide, for example, and this includes 5 per cent of ferrous oxide, the summation will be +0.5 per cent in error. If 15 per cent of ferrous oxide is determined and this includes 5 per cent of ferric oxide, then the summation will be -0.6 per cent in error. To test these errors in actual summations analyses have been selected in which the iron, wholly as one oxide or the other, is greater than 10 per cent and in which magnesia is less than 15 per cent. Magnesia can not be set at

* Gooch, F. A., and Austin, M., *The Constitution of the Ammonium Magnesium Phosphate of Analysis*, this Journal, 4th ser., vol. vii, p. 187, 1899.

a lower figure because rocks which contain large amounts of iron-bearing minerals are commonly rich in this element. The results are as follows:

Oxide determined	Number of anal.	Ave. summation
Ferric oxide	96	100·13
Ferrous oxide	21	100·04

The average summation for the analyses in which only ferric oxide was determined is the same as the general average, whereas it would be expected to be distinctly higher. An additional plus error due to magnesia would also be expected as a number of the analyses are of inferior quality. The failure of the average summation to show a positive error is no doubt largely due to the actual presence of little, if any, ferrous iron. The basic rocks used in this calculation are especially susceptible to alteration, actually shown by the large amount of water many of them contain, and the ferrous oxide has been raised to ferric form. The average summation for the analyses in which only ferrous oxide was determined is below the general average, an error in the right direction but hardly of significant size unless the summation has been raised by the plus error of magnesia. The result of this test is considerably vitiated by the inferior quality of some of the analyses, taken in connection with their small number. For example, two analyses of the same rock, by the same analyst, have summations of 99·15 and 100·51 per cent. This brings out the point, which will be considered later, that the personal errors of the analyst are sufficiently great to mask any error arising from good analytic methods when the number of analyses averaged is small.

It is possible that the minus error in silica finds expression in the silicic group of rocks (granites and rhyolites), which on the average contain about 70 per cent of this oxide. For example, 135 superior analyses of rocks in this group, selected at random, have an average summation of 100·04 per cent as compared with 100·13 per cent for the general average. The difference may be explained by assuming an actual loss of silica. Such a loss is not unlikely, because many of the analyses, on which the above average is based, were made before the present refinements in the determination of this oxide were introduced.

The foregoing considerations indicate that by far the commonest errors which affect the summation of analyses are of the analyst's own making. The trouble is not so much with methods as with the analyst's ability to use them. Such errors are illustrated by the results of a single chemist's work on rocks of nearly identical composition. The following

examples will suffice: (1) 9 analyses of similar rocks showing summations from 99·86 to 100·54 per cent; (2) 7 analyses, 99·59–101·00; (3) 5 analyses, 99·49–101·05; (4) 8 analyses, 99·86–101·16; (5) 7 analyses, 99·35–100·77; (6) 20 analyses, 99·58–100·72; (7) 21 analyses, 98·85–101·68. The range in the last example is 2·83 per cent and for this analyst's entire work on rocks of almost identical composition it is 3·96 per cent. This, of course, is an extreme example. Commonly the range of an analyst's summations will fall inside of 2 per cent. In general, as shown by the analyses used in this study, the range is from 97 to 103·5 per cent, or 3 per cent and more either side of the general average of 100·13 per cent.

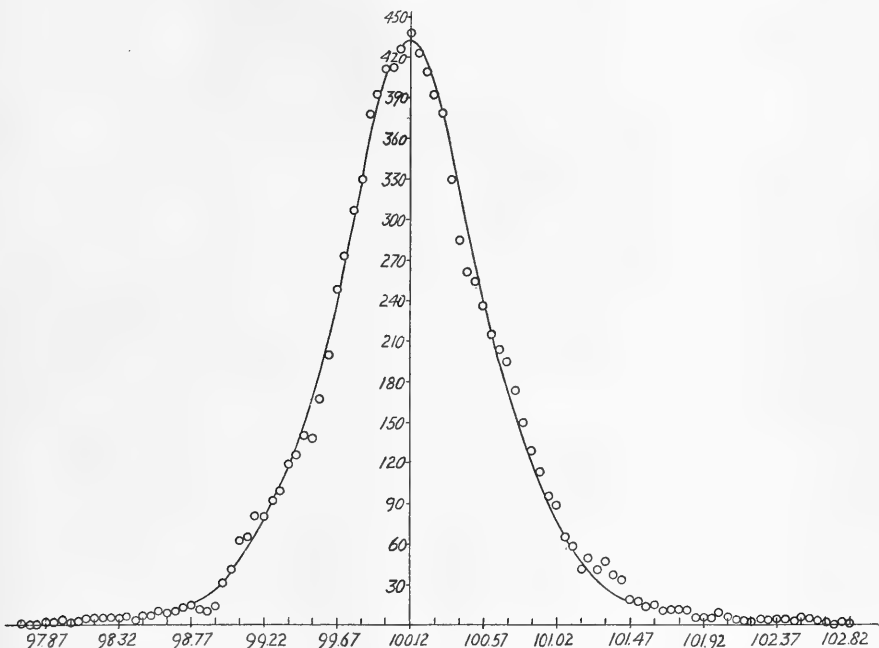
The individual analyst's errors are generally of two kinds. There is commonly a constant error represented by the difference between the analyst's average summation and the general average. There are always accidental (residual) errors represented by the differences between an analyst's single summations and his own average summation. The constant error is of small size compared with the accidental errors. In two-thirds of the above cases it is less than 0·2 per cent and the largest is 0·53 per cent. The accidental errors may be as large as 2 per cent either side of the average, although the great majority range from 0·5 to 0·75 per cent.

The chances appear even that the constant error may be either plus or minus. Thus out of 43 analysts all of whom have made over 15 analyses, 21 have a plus error averaging 0·21 per cent, 20 have a minus error averaging 0·17 per cent, and 2 have no error. The chances are even that the accidental errors will be either plus or minus in so far as they represent errors which lie in analytic methods. The accidental errors due to other causes, such as the incomplete washing or collection of precipitates, may be either plus or minus, apparently with equal chance. It thus appears that the errors which affect the summation of analyses for the most part are evenly distributed and consequently the probability curve for summations will be symmetrical. And it would seem the most probable assumption that this relation holds generally true.

However, whether summations in general are evenly distributed or not will depend on whether the proper unit of measure is employed. Analytic results are expressed to the hundredth place of decimals—not to mention the thousandth place. But a unit of measure (difference) of 0·01 per cent is of no significance. A difference of 0·05 per cent, the unit of Table 1, is below significant size. What then is the unit of most significant size? The requirements are that it shall show a maximum of the same value as the general average (100·13) and shall result in an even distribution of summations either side of the maximum.

This unit has been found by taking different sized units, from necessity, as multiples of 0.05 per cent, and determining which gives the best distribution. It is thus found that a unit of 0.15 per cent most nearly meets the requirements for the entire range of summations. The units of 0.20 and 0.25 per cent also produce a symmetrical distribution between the restricted limits of 99.50 and 100.74 per cent, which is better than that given by the 0.15 per cent unit. As three-quarters

FIG. 1.



of all summations fall within the foregoing limits there is practically little choice between the 0.15, 0.20, and 0.25 per cent units. A study of a larger number of analyses than here used might show the 0.15 per cent unit to be less suitable than the 0.20 or possibly the 0.25 per cent unit. The 0.15 per cent unit has been used to show the distribution of summations in general and the 0.25 per cent unit has been chosen, purely as a matter of convenience, to show the distributions for individual analysts which are later given.

For the unit of 0.15 per cent there are three possible combinations of the 0.05 per cent unit. The values for these three combinations have been plotted, as is customary, and a symmetrical curve has been fitted to them, as shown in fig. 1. In this figure the ordinates are the actual number of analyses, but

in those following they are percentages of the total number of analyses; in all the figures the summation groups are plotted by their mean value.

In general the departures from the fitted curve would appear small in view of the fact that the analyses (1) are the work of some hundreds of different chemists; (2) that they cover a period of 32 years, although the great majority fall in the last 6 years of that period, during which time many changes in methods of analysis were made; (3) that there is the certainty of some constant errors, and a possibility of others being present; and (4) that all the summations are not a matter of pure chance. Such departures as are shown are to some extent, though not wholly, due to the unit of measure being below significant size. This is evident when the data are plotted by the 0.20 per cent unit; the irregularities are much smoothed out, although the curve as a whole becomes slightly asymmetric.

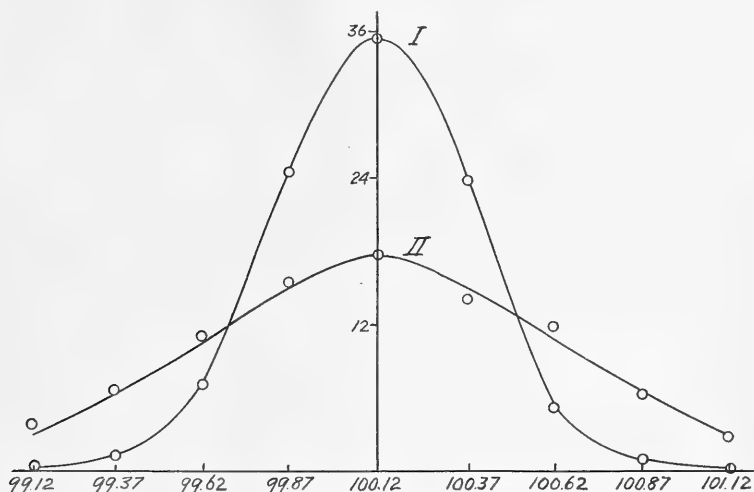
The different proportions of the entire number of analyses which may be expected to fall into the several groups of summations on the basis of the 0.15 per cent unit are given below. Corresponding figures are also given for groups by differences of 0.25 per cent on the assumption of an entirely symmetrical distribution.

TABLE II.

0.15 per cent unit		0.25 per cent unit	
Summation groups	Proportion of analyses	Summation groups	Proportion of analyses
100.05-100.19	12.8%	100.00-100.24	20.8%
100.20-100.34	11.8	100.25-100.49	17.0
99.90-100.04		99.75-99.99	
100.35-100.49	9.6	100.50-100.74	10.5
99.75-99.89		99.50-99.74	
100.50-100.64	7.1	100.75-100.99	6.0
99.60-99.74		99.25-99.49	
100.65-100.79	5.1	101.00-101.24	3.1
99.45-99.59		99.00-99.24	
100.80-100.94	3.6	101.25-101.49	1.3
99.30-99.44		98.75-98.99	
100.95-101.09	2.4	101.50-101.74	.6
99.15-99.29		98.50-98.74	
101.10-101.24	1.5	Beyond above limits	2.2
99.00-99.14			
101.25-101.39	.8		
98.85-98.99			
101.40-101.54	.5		
98.70-98.84			
101.55-101.69	.3		
98.55-98.69			
101.70-101.84	.2		
98.40-98.54			
Beyond above limits	1.5		

The general distribution curve (fig. 1) is based, of course, on the work of many analysts. Some of these, however, have contributed much more greatly than others. This is particularly true of the chemists of the United States Geological Survey; fully one-third of all the analyses here used have been made by them. Thus a distribution curve for the summations of the analyses made by the Survey chemists may be drawn. Such a curve for the work of five Survey chemists is shown by I, fig. 2. For comparison the distribution curve (II) for the work of all chemists, exclusive of those five analysts, is

FIG. 2.



added. The number of analyses used for I is 1,012; for II it is 2,497. For convenience the analyses are grouped by differences of 0.25 per cent, the significance of which unit has been noted in an earlier paragraph.

Clearly the Survey chemists have a much larger proportion of summations at or near the maximum than have other chemists. The relative percentages of analyses falling in the several summation groups are as given on the following page.

The superior results as to summation shown by the chemists of the U. S. Geological Survey are due to several reasons among which not the least is the experience gained from continuous work. Also, poor analyses (supposing such may occasionally be made) are evidently not allowed to leave the laboratory until their errors have been found and corrected. And it may be said that if all chemists followed this same

Summation groups	Proportion of analyses	
	U. S. G. S. chemists	All others
99·00– 99·24	·8	4·2
99·25– 99·49	1·6	6·6
99·50– 99·74	7·5	11·0
99·75– 99·99	24·4	15·9
100·00–100·24	35·7	17·7
100·25–100·49	22·9	13·9
100·50–100·74	5·4	12·1
100·75–100·99	1·7	6·8
	<hr/>	<hr/>
	100·0	88·2
Beyond above limits	0·0	11·8
	<hr/>	<hr/>
	100·0	100·0

practice their distribution of summations would more nearly approach that of the Survey chemists. In fact, the lower grade for the work of other chemists is due to the inexperience of many of the analysts. It is absolutely essential for a beginner to make analyses in duplicate, no matter what may be the nature of the rock, until he can secure accordant results. The writer has been told by a teacher of quantitative analysis that out of several hundred students the number who had obtained uniformly good results could be counted on the fingers of one hand. As Hillebrand has stated, "too great stress can not be laid upon the importance, especially for the analyst of limited experience, of consistently testing most of his final precipitates and filtrates as carefully as possible in order to be sure, on the one hand, that the substances reported by a given name are wholly such and, on the other, that all is reported. In no other way can an analyst so soon acquire the needed confidence in himself and his methods."*

A comparison of the distribution of summations for all other chemists with that for the five chemists of the U. S. Geological Survey (fig. 2) shows beyond argument how great is the room for improvement in the general quality of silicate rock analysis. The efficiency of the Survey chemists, which is fairly expressed by their distribution curve for summations, may well be taken as the standard.

An idea of the general quality of silicate rock analyses may also be obtained from the proportion of analyses that fall within certain proposed limiting summations, as shown in the following table:

* Op. cit., p. 28.

Limits	Proposed by	Proportion of analyses in
99·75–100·50	Hillebrand*	55
99·75–100·75	Hillebrand†	66
99·50–100·75	Washington‡	76

Hillebrand says: "Given the purest obtainable reagents, an ample supply of platinum, facilities for working, and a reasonably clean laboratory, there is little excuse for the failure on the part of a competent chemist to reach a summation within the limits 99·75–100·50 per cent."§ Washington states: "If, therefore, the analysis of a rock is satisfactorily complete, there is no excuse . . . for a summation that does not fall within the somewhat liberal limits here assigned."|| Interpreted in the light of these statements the figures in the last column of the above table are a striking commentary on the quality of a large proportion of the analyses of igneous rocks. Dr. Hillebrand's narrower limits are presumably based on his own experience; 90 per cent of his summations fall within them. For the work of the chemists of the U. S. Geological Survey, exclusive of Dr. Hillebrand, the proportion is 77 per cent. For all chemists, exclusive of those of the Geological Survey, the proportion is less than 50 per cent. These limits of 99·75–100·50 per cent, therefore, might well be considered too narrow; yet the writer prefers them because they furnish an additional stimulus to good work. And, indeed, they are of little value, and may be actually harmful, except when looked at in that way.

Having considered the general problem, the distribution of the summations of individual analysts may now be taken up. From a practical standpoint—improvement in analytic skill—such examples are most interesting.

As already stated, an analyst may have, in addition to the ever-present residual errors, a constant personal error which causes his average summation to be either above or below the general average. The following examples (fig. 3) show the effect of such errors in comparison with a normal curve. In this figure, and those following, the coördinate points are connected simply by straight lines, as sufficient for purposes of illustration. The number of analyses in each summation group is expressed as a percentage of the total number in each case so that the results for different analysts may be comparable.

* Bull. U. S. G. S., No. 148, 1897, p. 62.

† Bull. U. S. G. S., No. 422, 1910, p. 28.

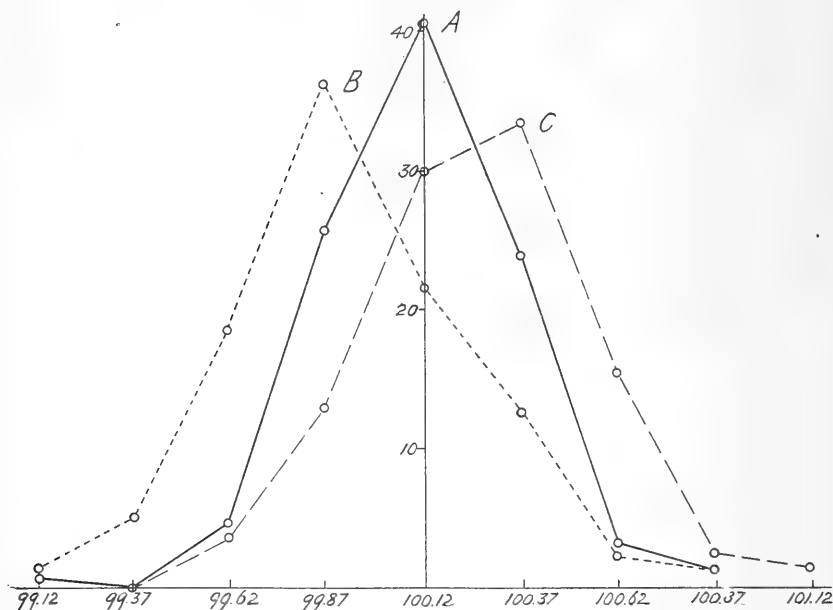
‡ Prof. Paper, U. S. G. S., No. 14, 1903, p. 34.

§ Bull. U. S. G. S., No. 422, 1910, p. 28.

|| Idem, p. 36.

As may be seen, analyst A has a very symmetrical distribution of summations as 28.5 per cent of the analyses have summations above and 31.3 per cent below that of the maximum group. His average summation of 100.11 per cent practically coincides with the general average, the constant error being only 0.02 per cent. Also the proportion of analyses (40.2) falling in the group of maximum frequency is high. In fact, having regard for the large number of analyses made by this chemist, this proportion may be considered as high as is obtainable in ordinary practice. Analyst B has an evident constant minus

FIG. 3.



error; it amounts to 0.22 per cent, as his average summation is 99.91. The constant error is, indeed, sufficiently large to throw the group of maximum frequency to 99.75–99.99 per cent. The distribution curve of B is somewhat asymmetric and a larger proportion of summations lie above the group of maximum frequency than below; the percentages are, respectively, 37.8 and 25.0. The proportion of summations (36.4) in the maximum group is good. Analyst C has a constant plus error of 0.12 per cent, his average summation being 100.25. His group of maximum frequency is 100.25–100.49 per cent, but the group 100.00–100.24 per cent contains nearly as large a proportion of analyses. The actual maximum for the fitted

curve thus would lie between these two groups and the curve would be flatter topped than those of A and B. Disregarding this fact, it may be noted that 46·8 per cent of C's summations lie below his actual group of maximum frequency, whereas 19·5 per cent are above. It will be observed that both B and C, whose groups of maximum frequency are, respectively, below and above the average group of 100·00–100·24 per cent, have the larger proportion of summations on the side of their maximum group which is toward the general average of 100·13 per cent.

The three curves of fig. 3 are based on a sufficiently large number of analyses in each case to make them fairly reliable. There is no great choice between the curves as to form, although that of A is evidently better than those of B and C. The work of these three analysts has been chosen for illustration because it typifies certain general features which may be stated as follows:

1. When the group of maximum frequency, on the basis of the 0·25 per cent unit, coincides with the average group (100·00–100·24 per cent), then (1) the number of analyses in the groups above and below that of maximum frequency will be equal, or (2) commonly a greater proportion will lie either above or below as the case may be. That is to say, most analysts have a slightly asymmetrical distribution of summations about the maximum which indicates the existence of a "personal equation." In general, however, the number of analyses on opposite sides of the maximum group should be equal. This is approximately true for the work of those analysts, fourteen in number, who fall in this category, the figures being 32·3 per cent above and 31·5 per cent below.

2. When the group of maximum frequency lies below the common maximum group then a larger proportion of summations will lie above the group of maximum frequency. Six out of eight analysts whose maximum group is below the average maximum group show this feature. For the eight analysts taken together 40·9 per cent of their summations are above and 21·8 per cent are below their group of maximum frequency.

3. When the group of maximum frequency lies above the average group then a larger proportion of summations will lie below the group of maximum frequency. This feature is shown by all the analysts, nine in number, who fall in this category. The proportion of summations are 50·2 per cent below and 18·9 per cent above their group of maximum frequency.

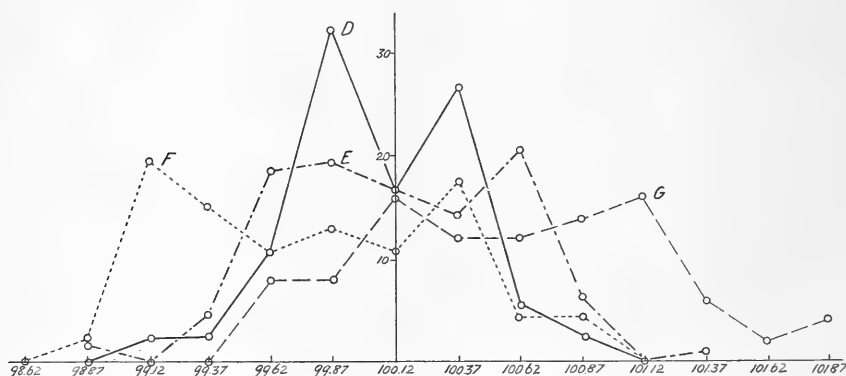
The foregoing characteristics may be taken as guides for testing the normality of the distribution of an analyst's summations. The explanation of the relations noted under (2) and

(3) would seem to be that an analyst naturally works toward the general average rather than away from it.

Distribution curves with a single maximum, as illustrated at their best in fig. 3, are the common type. A less common type is a double distribution curve—one with two maxima. Triple distribution curves, due to pure chance, probably do not occur.

Several examples of double distribution curves are shown in fig. 4. There is no doubt as to the reality of such distributions, the data are ample. In fact, the best curve of the four (D) rests on the smallest number of analyses. Just what conditions influence an analyst to get summations thus distributed

FIG. 4.



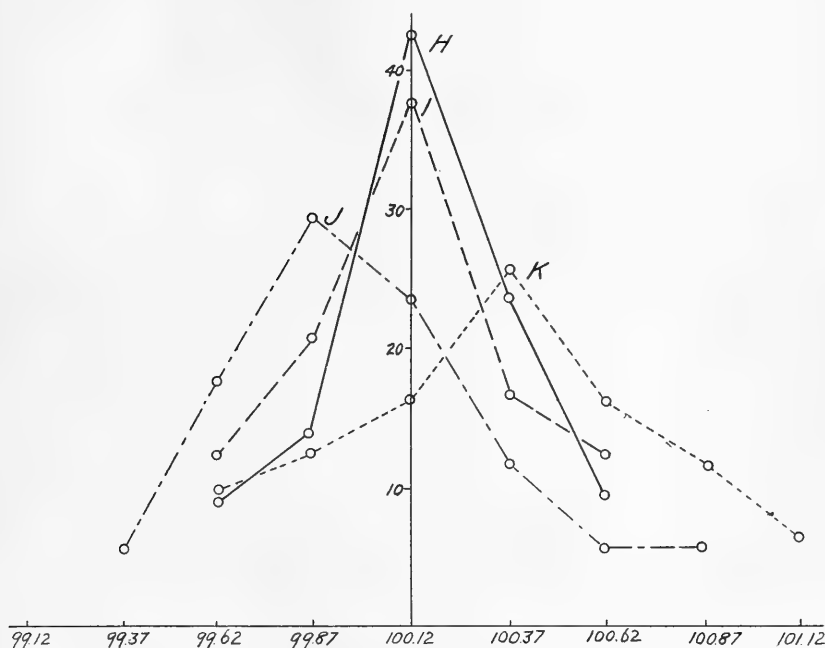
is difficult to say. They may be entirely personal, and the problem is then one for the psychologist, or they may result from such causes as changes in analytic methods, technic or quality of reagents, or to differences in the composition of the rocks analyzed.

Referring to fig. 4, it is seen that analyst D has larger proportions of summations in the two groups lying either side of the common maximum group than in that group itself. His tendency, also, is to get more summations in the lower group (99.75–99.99) than in the higher (100.25–100.49). The distribution of the summations under the circumstances, as shown by the form of the curve, is excellent. It must be concluded that such results are not in any sense haphazard. The tendency of analyst E toward double maxima is less marked than that of D. This analyst's upper maximum is the group 100.50–100.74 per cent, his lower is strictly in 99.75–99.99 per cent, but practically covers that group and the next lower. His maxima are thus farther apart than those of D and his

summations are more uniformly distributed between his two maxima. However like D, he has more summations in the lower maximum group than in the upper one. Analysts F and G have distributions which are quite similar, although F's summations lie largely on the negative side of the general axis (100.13 per cent), whereas those of G are largely on the positive side.

The foregoing double probability curves may be resolved into their two component single probability curves and it then

FIG. 5.



appears that the two parts may be classified under the three heads noted in an earlier paragraph, practically all falling under (2) and (3).

A distribution of summations to be significant must rest, of course, on sufficient data, and this is essentially true for the examples already cited. The number of analyses necessary to give such a result will vary widely, depending upon the analytic skill of the individual chemist. The minimum number can be determined approximately by examining the work of different analysts. In fig. 5 are given four examples to show that a very good distribution of summations, as indicated

by the symmetry of the curves, may be obtained from as few as 18 analyses (J) and not over 30 (K). The number of analyses for H and I are about midway between those for J and K.

The curves in the above figure are about as symmetrical as those shown in fig. 3, although based on very much smaller numbers of analyses. That none of the curves at their extremities approach the abscissa axis closely is due to the latter fact. For example, one analysis equals 5 per cent of 20 analyses so that if no more than two analyses fell in a limiting group they would equal 10 per cent as plotted on the diagram. The curves have not been extended to zero ordinate values in order to emphasize the limiting summation groups.

The distribution of summations of analysts H and I is distinctly better than for J and K. In fact H has a greater proportion of summations in his maximum group than analyst A (fig. 3); I has a greater proportion than B or C. The limits of their summations, also, are more restricted than for either A, B, or C. These facts, in connection with the small number of analyses, make it practically certain that analysts H and I exercised more than usual care in their work. They may have made some of their analyses in duplicate as well as made special redeterminations in some instances. Such a procedure means, of course, that their results have more than the average chance of being good. Analysts H and I, then, almost certainly could not obtain such favorable results on a large amount of work. It seems likely that the distribution shown by analysts J and K, disregarding the constant errors, more nearly represents the best that should be expected in ordinary practice with a small number of analyses.

The foregoing examples (figs. 3, 4, and 5) show some of the more symmetrical distributions of analyses which have come under the observation of the writer. They indicate, for the most part, what may be expected in good analytic work.

A study of the work of 43 analysts indicates the following chances in favor of a more or less symmetrical distribution of summations:

1. When the number of analyses is over 35, the chances are entirely in favor.
2. When it is between 20 and 35, the chances are as 4 : 5.
3. When it is between 15 and 20, the chances are as 2 : 3.

Below 15 analyses the chances are almost wholly against a symmetrical distribution so that this number is the minimum for a test of this character.

For distributions with a single maximum the chances are about 1 : 3 that the group of maximum frequency will fall outside the average group (100.00–100.24 per cent).

It also appears that the same chances hold for the occurrence of distributions with double maxima.

It would be possible to determine with considerable accuracy from the work of Dr. W. F. Hillebrand, because of its magnitude, what the chances are in favor of various types of symmetry. The results, however, would apply only to the work of analysts whose skill equals that of Dr. Hillebrand. The number of such analysts is, unfortunately, too small to compensate for the labor involved in the calculation of results. For example, from a study of the work of analysts in general the chances appear about 1 : 3 for the occurrence of double maxima, whereas on the basis of Dr. Hillebrand's work they are about 1 : 15. The discrepancy is due in part, certainly, to the lower grade work of a considerable number of the chemists whose analyses were studied.

There is, presumably, a fairly close relationship between the amount of work a chemist does and his technical skill. No doubt there are many analysts whose skill, and reputation, would improve noticeably with increased work. It is unfortunate that silicate rock analysis is so time-consuming that it has become customary to depend on single determinations of constituents for a final result. This custom works out most unfavorably with those chemists who make but a few analyses. It would redound to their credit, and be an excellent thing for petrology, if these analysts did all their work in duplicate. Mineral analyses commonly have been made in duplicate because of the importance of an accurate result for establishing a formula. It is by no means impossible that increased knowledge of rock composition, derived from physico-chemical study, eventually will call for duplicate determinations in rock analysis. At least it will call for work of greater accuracy than much that has been done in the past or is, indeed, being done at present.

The probable error of his single summations, and to a less extent that of his average summation, indicates with considerable accuracy the technical skill of the chemist.* It is not a complete measure because there are possible errors which do not affect the summation, a very persistent one being the incomplete separation of magnesia and alumina. The number of a chemist's analyses has a marked effect on the probable error of his average summation because the calculation involves the quantity $N \times N - 1$. The number affects the probable error

* It will be recalled that the formula for the probable error of an arithmetical mean is $E_a = 0.6745 \sqrt{\frac{[r^2]}{N(N-1)}}$, whereas for a single measurement

$E = \sqrt{\frac{r^2}{N-1}}$, where r = residual error and N the number of measurements.

of a single summation only so far as a large amount of work conduces to more accordant results than a small amount. Thus the difference between the probable error of the average summation of a chemist who has done much work and of one who has done little may be as great as 200 per cent, whereas the difference in the probable errors of their single summations may not exceed 25 per cent. For this reason the probable error of a single summation is the more valuable guide to the quality of a chemist's work.

The probable errors for single summations and the average summations of 43 analysts, who have made 15 or more analyses, weighted according to their relative amount of work, are :

Single summation, ± 0.30 per cent.
Average summation, ± 0.02 per cent.

The effect of a considerable difference in the number of analyses on the values of the probable errors is shown by the following figures :

1. For those chemists who have made 50 or more analyses. Single summation, ± 0.20 per cent ; average summation, ± 0.01 per cent.

2. For those chemists who have made between 15 and 50 analyses. Single summation, ± 0.40 per cent ; average summation, ± 0.07 per cent.

It is the opinion of the writer, based on all available data, that the probable error of ± 0.30 per cent for a single summation furnishes a fair guide for judging a chemist's technical skill, so far as it may be judged by the summation of analyses. If a closer estimate of a chemist's work is desired, then the values based on the amount of work done should be used.

To give point to the foregoing general values, the probable errors, and also the constant errors, for the work of those chemists whose distribution curves have been presented in figures 3-5 may be stated :

Analyst	No. of anal.	Constant error	P. e. single sum.	P. e. ave. sum.
A	450	-0.02	± 0.16	± 0.01
B	140	-0.22	.26	.02
C	77	+0.12	.20	.02
D	37	-0.08	.24	.04
E	147	-0.02	.30	.02
F	46	-0.39	.39	.06
G	50	+0.45	.43	.06
H	21	0.00	.18	.04
I	24	+0.01	.20	.04
J	17	-0.11	.26	.06
K	31	+0.19	.28	5

A small probable error for a single summation means that the summations as a whole fall within narrow limits and that a large proportion are in the group of maximum frequency, whereas a large probable error indicates the opposite. As a general rule a small constant error is associated with a small probable error for a single summation. A large constant error is almost always associated with large probable errors for both a single and also the average summation, as shown by analysts F and G and to a less extent by B and K. When particularly large it is an almost sure mark of inferior analytic skill. In but one case out of ten, which have come under observation, has a large constant error been accompanied by small probable errors.

Referring to the probable errors for single summations, all are below the average value of ± 0.30 per cent except those of analysts F and G, and one (E) which is on the average. Probable errors of ± 0.18 – 0.26 per cent are not uncommon for chemists who have made less than 30 analyses, thus comparing well with the value of this error for analysts A, B, and C who have done much work. For this reason the single value of ± 0.30 per cent has been adopted rather than the two values of ± 0.20 and ± 0.40 per cent, depending upon a large or small number of analyses.

As already stated, the size of the probable error for the average summations depends on the number of analyses. It must be judged accordingly. Thus the error of ± 0.02 per cent for B and C is about equal to the value of ± 0.01 per cent for A. Likewise the error of ± 0.04 per cent for analysts D, H, and I should be considered of equal value to the smaller errors for A, B, and C.

It may be said in conclusion, then, that a probable error for a single summation much less than ± 0.30 per cent in connection with a probable error for the average summation of ± 0.01 – 0.03 per cent, when the number of analyses is large, or of ± 0.04 – 0.06 per cent when it is small (less than 50), indicates good technical skill on the part of the chemist. On the other hand, if the probable error for a single summation is much over ± 0.30 per cent and the error for the average summation is in excess of the upper limits just given, then a lack of technical skill is indicated.

Peabody Museum, New Haven, Conn.

ART. XVIII.—*Coniferous Woods of the Potomac Formation*;
by E. W. SINNOTT and H. H. BARTLETT.

THE Potomac formation is of particular interest to botanists because of the rich flora which it contains. Its leaf impressions have become known through the labors of Fontaine,* Ward,† and Berry,‡ but the fossil woods have attracted far less attention. The only important contribution to our knowledge of the latter was made in 1889 by Knowlton,§ who described from silicified material four species of Cupressinoxylon (*C. pulchellum*, *C. McGeei*, *C. Wardi*, and *C. columbianum*). The Potomac formation contains far more lignite than silicified wood, but no one has thus far studied it with satisfactory results. After examining many specimens Knowlton wrote: "From the abundance of the genus Cupressinoxylon in the Potomac formation, as shown by the silicified examples, it is probable that most of the lignite may be also of this genus, particularly as there is in many cases a marked resemblance, so far as I am able to interpret the distorted structure, between it and some of the species described from silicified specimens. This is, however, little more than conjecture." Only recently Berry has said: "Both lignite and petrified wood, either silicified or ferruginized, are common at most horizons in the Potomac beds, but very little effort has been devoted to their collection or study. The lignites as far as they have been examined are coniferous but so much distorted by pressure and by decay before fossilization as to be of but little scientific value. The silicified materials, while in a somewhat better state of preservation, leave much to be desired. Of a large number of such sections in the hands of the writer only a very few are sufficiently well preserved to be determinable. The ease with which fragments of silicified wood may be reworked from formation to formation also minimizes their stratigraphic and phylohistorical value."

One of the writers has recently seized an opportunity to secure abundant material of lignite and charcoal from the Patuxent horizon of the Potomac formation at two localities in the District of Columbia. A deep and extensive excavation for the new Central High School of Washington at 11th Street

* Fontaine, W. M., The Potomac or younger Mesozoic Flora, Mon. U. S. Geol. Surv., xv, 1889.

† Ward, L. F., The Potomac formation, Fifteenth Ann. Rep. U. S. Geol. Surv., pp. 307-397, 1895.

‡ Berry, E. W., Several papers, summarized and referred to in Maryland Geol. Surv., vol. iv, Lower Cretaceous, Baltimore, 1911.

§ Knowlton, F. H., Fossil wood and lignite of the Potomac formation, Bull. U. S. Geol. Surv. No. 56, 1889.

and Florida Avenue exposed several plant beds, and a deposit of blue clay which contained a great deal of lignite in the form of prostrate logs and branches. The lignite at this locality had the appearance of an accumulation of drift wood; there were no leaf impressions directly associated with it.

On account of the very irregular bedding of the Potomac strata it is quite useless to attempt to generalize a section even for so small an area as the Central High School locality. The excavation was made on a somewhat steep slope and was terraced so that the entire section could not be seen from any one point. At the highest elevation on the site (alt. 183.5 ft.) the section was as follows:

"Lafayette."	Reddish loam	2 ft.
	Yellowish gravelly loam	4 ft.
	Varicolored unstratified clay ...	11.5 ft.
	White clay (below 166 ft.)	?
Patuxent.		

The face of the next terrace (beginning at alt. 166 ft.) gave the following section:

Patuxent.	Varicolored clay	5 ft.
	White clay, grading to blue, containing lignite at base	14.5 ft.

A few feet away the section was continued (below 151 ft. alt.) as follows:

Patuxent.	Blue lignitic clay	1 ft.
	Ferruginous sand	3 ft.
	White and colored arkosic sand ..	7 ft. +

At another point in the excavation the white arkosic sand, continuous with that at 140 ft. in the base of the above section, had a depth of 20 ft. and rested upon a thin continuous laminated layer (varying from less than an inch to 3 ft. in thickness) of light brown or pinkish clay, exceedingly rich in leaf impressions. From this layer the following forms were identified:

Pteridophyta

Acrostichopteris pluripartita (Fontaine) Berry

(Abundant and characteristic. Known only from the Patuxent formation.)

Dryopterites virginica (Fontaine) Berry

(One specimen. Heretofore known with certainty only from the Patuxent formation near Fredericksburg, Virginia.)

Onychiopsis Goepperti (Schenk) Berry

(Very abundant and variable.)

Onychiopsis latiloba (Fontaine) Berry

Onychiopsis psilotoides (Stokes & Webb) Ward

(These three nominal species of *Onychiopsis* are found in the Arundel and Potapscu formations, as well as in the Patuxent.)

Cycadophyta

Dioonites Buchianus (Ettings.) Born.

(A widespread type, but in the Potomac known with certainty only from the Patuxent. A very abundant fossil at the Central High School site. Fine and characteristic specimens were obtained; the first unquestionable material from north of the Potomac River.)

Zamites tenuinervis Fontaine

Podozamites lanceolatus (L. & H.) F. Braun

Podozamites acutifolius Fontaine

Podozamites distantinervis Fontaine

(Numerous single leaflets, for the most part fragmentary, but obviously representing several different forms, are somewhat doubtfully identified with these nominal species of *Zamites* and *Podozamites*.)

Nilsonia densinervis (Fontaine) Berry

(A single small but well-preserved fragment. Known from the Patuxent and Arundel formations.)

Coniferæ

Nageiopsis zamiioides Fontaine

Nageiopsis angustifolia Fontaine

(Numerous leaves in an unsatisfactory state of preservation, none of them attached to twigs. Both species are known from all three formations of the Potomac group.)

Cephalotaxopsis magnifolia Fontaine

(Very doubtfully identified from one fragmentary leaf, which differs from all the other coniferous remains in having a very broad mid-vein.)

Brachyphyllum crassicaule Fontaine

(Scanty but satisfactory specimens.)

Arthrotaxopsis grandis Fontaine

(Both cones and foliage which, however, are not attached. The most abundant fossil of the beds. Twigs very slender, and indistinguishable from forms which have been called *Widdringtonites ramosus* (Fontaine) Berry. *Widdringtonites* is characterized by four-valved cones. From the manner of occurrence of our fossil, it seems highly improbable that the many-scaled cones which we have associated with it belong to any other form. Perhaps it is worth while to suggest that all of the so-called *Widdringtonites* of the Potomac is in reality *Arthrotaxopsis*.)

Sphenolepis Kurriana (Dunker) Schenk

(Next to *Arthrotaxopsis* and *Nageiopsis* the most abundant conifer.)

Sequoia ambigua Heer

(Scanty impressions, without cones.)

In addition to lignite, the clay at the Central High School site provided a fine collection of charcoal fragments, which had obviously been transported by wind or water from a forest fire. These fragments were unquestionably carbonized before they were buried, for they were associated with typical lignite derived from the same kind of wood. It must, therefore, be understood that the charcoal referred to in the following pages is charcoal in the usual acceptation of the word, and not the material sometimes called "carbonized wood" or "mineral charcoal."

The second locality where lignite and charcoal were collected is about half a mile from the first. In the improvement of Meridian Hill Park on 16th Street the well-known section at that place has been re-exposed. On account of weathering, the leaf impressions and lignite formerly collected there had long been inaccessible. The lignite-bearing bed at Meridian Hill is much more restricted than that at the Central High School site, but is in a way more interesting because of the fact that the lignified wood appears not to have been transported, but rather to have been buried *in situ*. The same layer which contains the lignite contains the leaf impressions which have been reported by other writers from "16th Street." The Meridian Hill section on 16th Street opposite Crescent Place is approximately as follows:

"Lafayette."	Red loam.....	1 ft.
	Red gravel containing bowlders...	5 ft.
	Red and yellow loam.....	8 ft.
	Coarse red gravel and bowlders, with iron crusts	8 ft.
	Lignitic clay with leaf impressions ..	3 ft.
Patuxent.	Green sandy clay	5 ft. exposed.

A few feet further north, at the point where the lignite and charcoal collections were made, the plant bed pinched out and passed under a layer of ferruginous arkosic sand, which formed a layer three or four feet thick between the pinkish clay plant bed and the overlying boulder layer. The writer has collected no satisfactory impressions at Meridian Hill except foliage and cones of *Arthrotaxopsis*, but Berry (l. c.) reports the following identifications:

Onychiopsis psilotoides (Stokes & Webb) Ward.

Podozamites distantinervis Fontaine.

Nageiopsis angustifolia Fontaine.

Arthrotaxopsis grandis Fontaine.

The plant bed is in places full of impressions which are unquestionably referable to *Nageiopsis*, although they are very badly preserved. Much charcoal may be found by careful

search, on the outside of lignified logs which were charred by fire before burial as well as in small fragments.

It is worthy of note that Dicotyledones are not represented at either locality. The beds are within a mile of the contact between the ancient crystalline rocks of the Piedmont region and the Cretaceous deposits, and represent the base of the Potomac formation as it is developed on the Maryland side of the Potomac River. No fossils were found which at all suggested the supposed primitive Dicotyledones which have been found in deposits of similar age near Fredericksburg, Virginia.

In the great majority of cases the lignitic material is very poorly preserved, having suffered much compression and distortion, but a few pieces were found which proved to be in excellent condition. In the large and unique collection of charcoal fragments, on the other hand, there are many beautifully preserved specimens, although the brittle tracheid walls are often considerably cracked and broken. Remains of fungus mycelia are of rather frequent occurrence. By careful embedding in celloidin thin sections of both lignite and charcoal were obtained. A study of the large amount of material at hand showed it to be composed of the two types, both of them coniferous, which are named and described below.

Podocarpoxylon McGeei (Knowlton) n. comb.

[*Podocarpoxylon* Gothan, Abh. konigl. preuss. geolog. Landesanstalt. Neue Folge, Heft 44, p. 103, 1905.]

Cupressinoxylon McGeei Knowlton, Bull. U. S. Geol. Surv. No. 56, p. 46, 1889.

Annual rings poorly marked. Wood parenchyma present but not abundant. Tracheids usually very broad, their radial walls provided with large bordered pits in one or more rarely two rows, pits in the latter case opposite. So-called "bars of Sanio" well developed. Pits from tracheid to ray generally one or two to the crossing field, large. Pore from rather small and obliquely vertical ("podocarpoid") to very large ("eiporig"). Rays thin-walled, pitless, frequently biseriate, and in many cases exceedingly tall, often attaining a height of sixty or more cells.

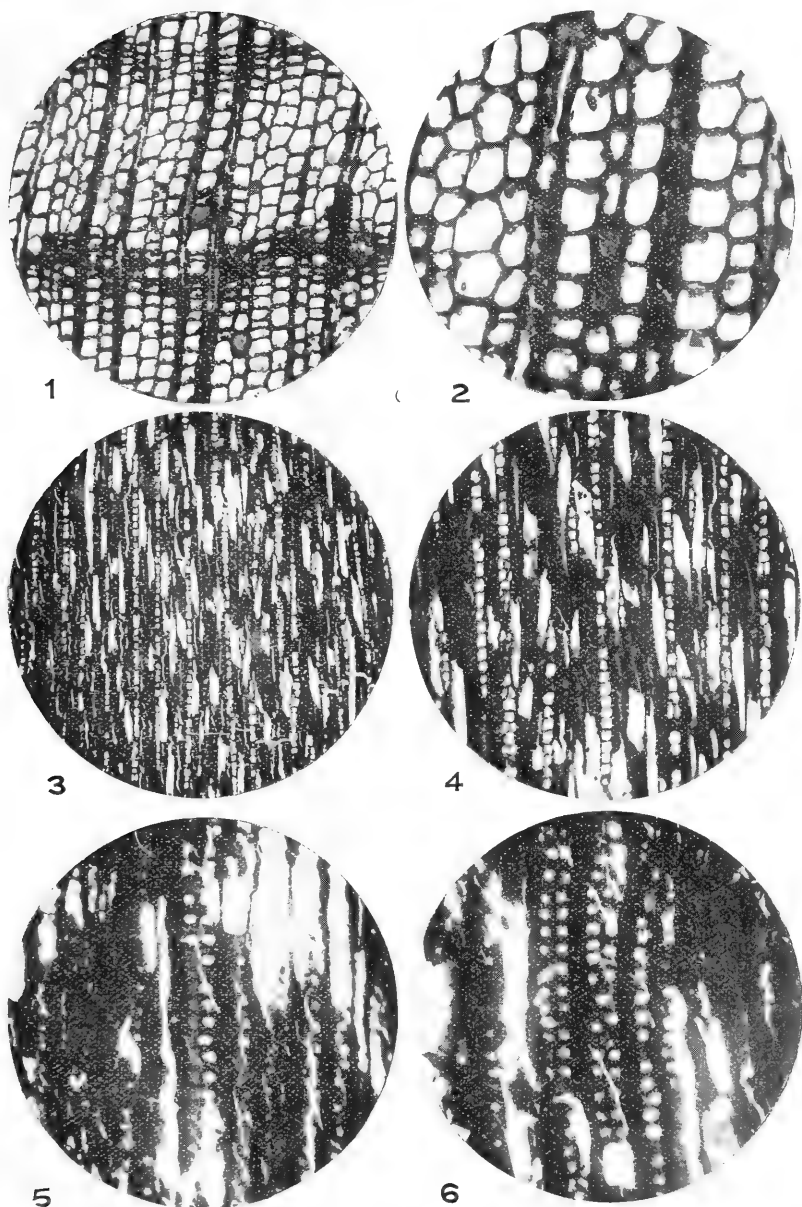
Localities: Central High School and Meridian Hill Park, Washington, D. C.

Horizon: Patuxent. (Lower Cretaceous.)

Structure.

The tracheids of *Podocarpoxylon McGeei* are unusually broad, averaging 35–40 to the millimeter in the transverse section. The annual rings vary greatly in width and are usually

FIGS. 1-6.



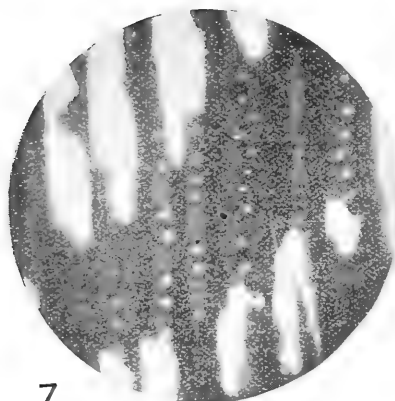
FIGS. 1-6. *Podocarpoxylon McGeei* (Knowlton), n. comb.

poorly marked. Wood parenchyma is scattered throughout the year's growth but not abundantly. As seen in radial section the tracheid walls display numerous large (rarely smaller) bordered pits usually in one row, though in the wider cells they are often in two rows and opposite. "Bars of Sanio" are well developed between the pits. Small tangential pits occur sparingly at the end of the year's growth. The walls of the medullary rays are thin and devoid of pitting. In the majority of cases there is but a single pit in each "crossing field" between tracheid and ray cell, although in the larger tracheids there are commonly two and rarely even three. The pit outline is generally large and elongated horizontally, sometimes big enough to cover almost the whole crossing field. The pore is either of medium size, a vertically or obliquely elongated opening, in which case the border of the pit is necessarily very wide; or the pore may be so much enlarged as nearly to equal the pit outline in dimensions, resulting in the reduction or even the disappearance of the border and the production of a huge "eipore." This enlargement may perhaps be sometimes due to conditions of preservation or, as in many of the living Podocarpaceae, it may be quite normal. The ray pitting may, therefore, be said to vary from "podocarpoid" to "eiporig," in the sense of Gothan. The most striking characteristic of the medullary rays, however, is the extreme height of many of them. The majority, as seen in tangential section, are from three to ten cells high, but scattered rather frequently among these, especially in certain of the specimens, are others which are very much taller, often running up to sixty and in one case even apparently to ninety cells in height. These very high rays are probably due to the linking up of shorter ones vertically, for several cases were observed where the top of one medium-sized ray was close to the bottom of another. As may be seen in the figures both of the transverse and tangential sections, a large percentage of the rays are biseriate.

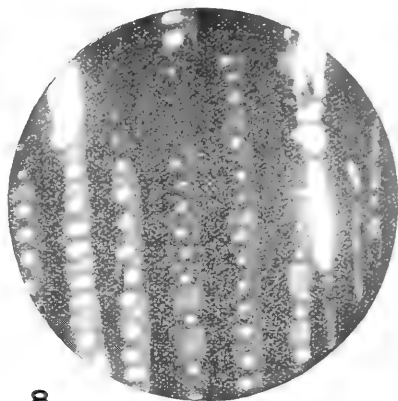
Relationships.

In the width of the tracheids, the character of the lateral ray pits and the height and frequently biseriate condition of the rays, this fossil so much resembles *Cupressinoxylon McGeei* Knowlton as to leave little doubt that the two are identical. One charcoal fragment possessing slightly narrower tracheids and smaller pitting displays certain resemblances to Knowlton's *Cupressinoxylon Wardi*, which was collected from near our localities (Railroad cut near Montello, D. C.) and may perhaps be identical with that species. It is so close to *C. McGeei*, however (in which some of the tracheids often show much smaller pits than others), that it seems best at present to place

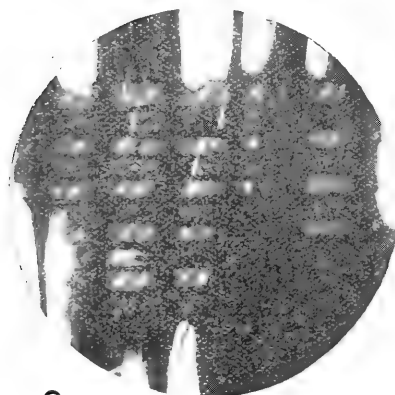
FIGS. 7-12.



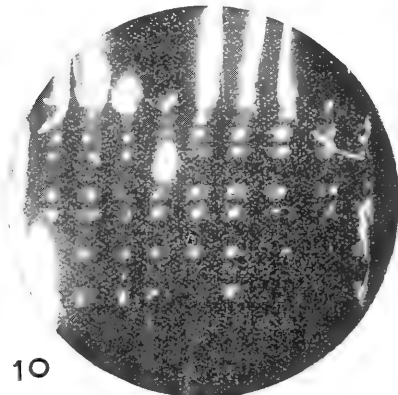
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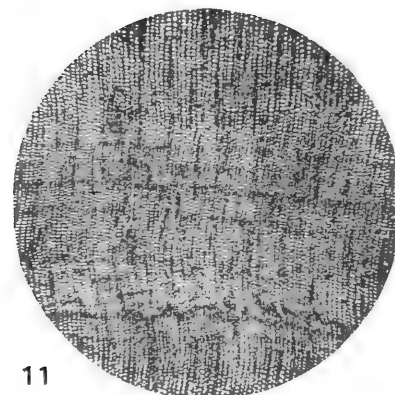
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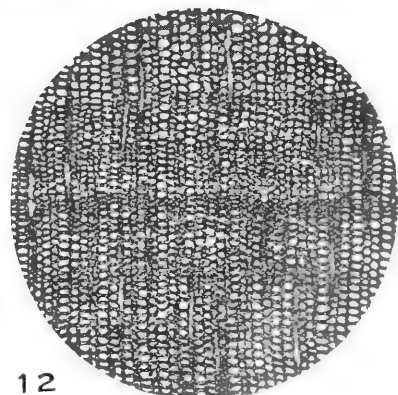
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FIGS. 7-10. *Podocarpoxylon McGeei* (Knowlton), n. comb.
FIGS. 11-12. *Paracupressinoxylon potomacense*, n. sp.

it under that species. It is suggested later in this paper that our *Podocarpoxylon* is the wood of *Nageiopsis*. If so, one might reasonably expect to find two or more distinct but similar types of wood corresponding to the different species of *Nageiopsis* which have been founded upon leaf impressions. On the contrary, it is possible that the difference between *Cupressinoxylon* (*Podocarpoxylon*) *McGeei* and *C. Wardi* is due to different growth conditions of the same species, as, indeed, the differences between the leaf impressions might also be.

The genus *Cupressinoxylon* was founded by Goeppert* to include woods in which vertical parenchyma is present in some abundance as opposed to *Cedroxylon*, where this tissue is absent. Gothan† has properly modified the limits of the genus to comprise those forms possessing not only wood parenchyma but also thin-walled, pitless ray cells, structures typical of the members of the *Cupressineae* to-day. Strictly on this basis our fossil would be placed under *Cupressinoxylon*, in agreement with Knowlton. Gothan (†), however, has proposed the name *Podocarpoxylon* for all woods with parenchyma and thin-walled rays which also possess few (usually one or two) lateral ray pits to the crossing field, each with a large outline and a pore varying from a medium-sized vertically or obliquely elongated opening ("podocarpoid") to one which is as large as the outline itself ("eiporig"). This general type is to-day mainly confined to the members of the *Podocarpineae*, similar structures outside this group being found only in certain of the soft pines, in *Sciadopitys* and in *Glyptostrobus*, in all of which there are other distinguishing characters. Since we have already shown that the ray structures in our fossil vary typically from "podocarpoid" to "eiporig," it should evidently be placed under *Podocarpoxylon*, if we are to follow Gothan. That it is an actual fossil representative of the *Podocarpineae* can not, however, be regarded as entirely certain, for some doubt has been cast on the value of Gothan's ray characters as definitely diagnostic of podocarpineous woods; and until our knowledge of the comparative anatomy of this tribe is much more extensive we can not hope to settle the point. Nevertheless, the frequency, among fossil forms, of this wood type with big-pitted rays, in comparison with its relative infrequency at the present day, is a noteworthy fact. A search, by no means exhaustive, through the literature reveals the following

* Goeppert, H. R., *Monographie der fossilen Coniferen*, *Naturkund. Verh. d. Holl. Akad. Wetensch.* Haarlem. Tweede Verzameling, 66 Deel. 1850.

† Gothan, W., *Zur Anatomie lebender und fossiler Gymnospermen-Holzer*, *Abh. königl. preuss. geol. Landesanstalt*, Neue Folge, Heft 44, Berlin, 1905.

forms (not including *Pinus*) which possess "podocarpoid" or "eiporig" pitting: *Cupressinoxylon* sp. of Hollick and Jeffrey* from Kreischerville, N. Y.; *Paracupressinoxylon* sp. of Miss Holden† from Cliffwood, N. J.; *Podocarpoxylon* spp., *Paraphyllocladoxylon* spp. and *Xenoxylon* spp. of Miss Holden‡ from the Jurassic of Yorkshire; *Phyllocladoxylon* sp., *Xenoxylon* spp., *Anomaloxylon* sp., *Protocedroxylon* sp., and *Cupressinoxylon* cf. *McGeei* of Gothan§ from the upper Jurassic of Spitzbergen and King Karl's Land. Gothan included this last species in *Cupressinoxylon* rather than in *Podocarpoxylon* because borders to the lateral ray pits seemed quite absent, a character which from Knowlton's figures of *C. McGeei* he believed to distinguish that species also. We have shown, however, that well-marked borders occur in material which is presumably identical with Knowlton's. (Unfortunately the type slides of Knowlton's species have been lost or misplaced and could not be consulted in the preparation of this paper.) One of the writers has also collected wood with this general ray structure from the (presumably) Jurassic of Southland, New Zealand.

This type of wood with big-pitted ray cells seems, therefore, to have been rather common and widely distributed during the Mesozoic. Not all the species cited, however, have been referred to the Podocarpaceae. It is significant that *Paraphyllocladoxylon* and *Xenoxylon*, from the absence of "Bars of Sanio" and the frequently alternating and flattened condition of the tracheid pits, are believed by Miss Holden to be araucarian in their affinities. She calls attention to the presence of "abortive" bars of Sanio in *Xenoxylon phyllocladioides*. The genera *Anomaloxylon* and *Protocedroxylon* of Gothan are also distinguished by tracheid pitting intermediate between araucarian and non-araucarian types. If such forms as these with large ray pits are indeed to be regarded as intermediate between the abietineous and cupressineous type and that of the Araucarineae, the conclusion suggests itself that the Araucarineae are related more or less closely to the Podocarpaceae. A considerable body of evidence derived from a comparative study of the reproductive structures has been brought forward

* Hollick, A., and Jeffrey, E. C., Studies of Cretaceous Coniferous Remains from Kreischerville, New York. Mem. N. Y. Bot. Gard. Vol. III, 1909.

† Holden, R., Contributions to the Anatomy of Mesozoic Conifers. No. 2, Cretaceous Lignites from Cliffwood, New Jersey; Bot. Gaz. 58: 163-176, 1914.

‡ Holden, R., Contributions to the Anatomy of Mesozoic Conifers. No. 1, Jurassic Coniferous Woods from Yorkshire, Ann. Bot. 27: 533-545, 1913.

§ Gothan, W., Die Fossilen Holzreste von Spitzbergen. Kungl. Svenska Vetensk. Akad., Handl., xlv, No. 8, 1910. Die Fossilen Hölzer von König Karls Land. Kungl. Svenska Vetensk. Akad., Handl., xlii, No. 10, 1908.

by one of the writers* in support of the contention that the araucarian conifers had their origin from some ancient abietineous stock by way of intermediate forms which were essentially like the Podocarpineae. If this contention is well founded, a large flora of podocarp-like forms in the Mesozoic, some of them araucarian in their affinity, a flora the existence of which the fossil record seems to indicate, is exactly what one would expect to find.

In this general argument as to the relationship between podocarps and araucarians, which brings in the whole vexed problem of the ancestry of the Araucarineae, there is one factor which has perhaps not been sufficiently emphasized, namely, the importance of habitat in determining preservation. It seems reasonable to infer that the Abietineae were as generally confined to temperate climates in the past as in the present. During most of the Mesozoic, however, a temperate climate appears to have been limited almost entirely to upland regions, and in these upland regions fossilization would rarely take place. The Araucarineae, on the other hand, are to-day tropical or subtropical in their distribution, and may always have been so. They certainly thrived in the hot lowlands of the Mesozoic, where conditions were favorable for fossilization. On this ground is it not possible to explain the comparative infrequency of typical abietineous remains throughout the Mesozoic and the great abundance of araucarians, a circumstance which has been one of the main supports of those who believe that the latter are more ancient in type than the former? May there not have been an abundant abietineous flora on the Mesozoic uplands which largely escaped preservation, but from which were developed the lowland tropical Araucarineae? It is significant in this connection that the Podocarpineae to-day are both temperate and tropical in their distribution and comprise both upland and lowland species, precisely what we should expect of a group intermediate between the temperate Abietineae and tropical Araucarineae.

But whatever hypothesis as to phylogeny we may adopt, it seems probable that the Podocarpoxyton type is characteristic of at least the great majority of the Podocarpineae to-day; and that this type was relatively more frequent in past ages. We have accordingly transferred *Cupressinoxylon McGeei* to *Podocarpoxyton*. If this wood is ultimately proved to belong to Nageiopsis, as we believe it does, anatomical evidence will have afforded striking confirmation of the affinity between Nageiopsis and Nageia which Fontaine adduced from foliage impressions alone.

* Sinnott, E. W., "The Morphology of the Reproductive Structures in the Podocarpineae; Ann. Bot., xxvii, 39-82, 1913.

Paracupressinoxylon potomacense n. sp. .

Annual rings poorly marked. Wood parenchyma abundant. Tracheids exceedingly narrow, their radial walls provided with a single row of small bordered pits. "Bars of Sanio" absent. Pits from tracheid to ray generally one to the narrow crossing field; if two, then one above the other. Pore narrow to rather wide, oblique. Rays thin-walled, pitless, very shallow, usually from one to three cells in height. Traumatic resin canals well developed.

Localities: Central High School and Meridian Hill Park, Washington, D. C.

Horizon: Patuxent. (Lower Cretaceous.)

Structure.

Paracupressinoxylon potomacense is represented in our collection only by lignite and was found most abundantly at the Meridian Hill Park locality. Its tracheids are very much smaller, averaging 100–120 to the millimeter in the transverse section, or only about a third as wide as those of *Podocarpoxylon McGeei*. Annual rings are very poorly marked. Wood parenchyma, very thin-walled, is abundant and scattered throughout the year's growth. Its cells are almost invariably filled with a resinous or mucilaginous substance. The pits on the radial walls of the tracheids are necessarily small and never occur in more than one row. They are numerous, especially towards the ends of the tracheids, but are very rarely flattened by mutual contact. Even in the best preserved material, "bars of Sanio" seem to be completely absent. The ray cells, like the wood parenchyma, are thin-walled and pitless. There are either one or two pits on the small crossing field between ray cell and tracheid, but these pits are generally large in proportion to the field. The pores are elongated obliquely or in some cases almost horizontally and are sometimes rather large. Most of the rays are very shallow, running from one to three cells in height, although a few are taller. We were fortunate enough to secure two specimens which, though not particularly well preserved, show indubitably the presence of healed wounds. Running back from the edges of the wound cap on either side is a tangential row of traumatic resin canals. Most of these have suffered from lateral compression, but that they are true resin canals is made clear by the radial section, which shows well-developed epithelial cells and tyloses.* In the

*Jeffrey has described and figured the occurrence of traumatic resin canals in an unnamed coniferous wood from the Potomac formation at Dutch Gap, Va., which is perhaps identical with ours, although the other characters are unknown. (Jeffrey, E. C., Wound Reactions of Brachyphyllum, Ann. Bot., xx, 383–394, 1906.)

vicinity of the healed wound the rays are much taller than in normal wood, sometimes ten cells high.

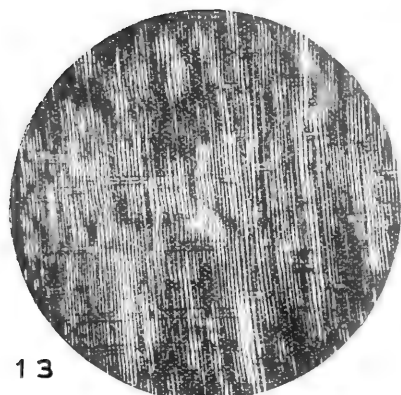
Relationships.

This interesting fossil apparently belongs to that ever enlarging group of forms which have been regarded as intermediate between Abietineae and Araucarineae. According to the definitions of both Goeppert and Gothan it would certainly be classed as a Cupressinoxylon, since it possesses both wood parenchyma and thin-walled rays; but those insignificant though taxonomically important structures, the so-called "bars of Sanio," seem to be quite lacking. The absence of these has been cited by Jeffrey, Sinnott, Miss Gerry, Miss Holden and others as an indication of araucarian affinity. Chiefly on this basis (but also from other evidence) a considerable number of genera and species, otherwise resembling Cupressineae, Taxodineae or Podocarpineae in their internal or external structures, are now treated as "masquerading" araucarians. So regarded are species of *Brachyphyllum*, *Geinitzia*, *Widdringtonites*, *Raritanian*, *Androvettia* and others by Hollick and Jeffrey (l. c.); *Araucariopitys* by Jeffrey*; *Paracedroxylon* by Sinnott† and *Paracupressinoxylon*, *Paraphyllocladoxylon*, *Metacedroxylon* and *Xenoxylon* by Miss Holden (l. c.). The occurrence of mutually flattened pits was regarded by Hollick and Jeffrey as the chief evidence of araucarian affinity. Jeffrey has since adopted the absence of "Bars of Sanio" as a much more reliable criterion. To be sure, this criterion must be used with caution in dealing with fossil tissues, since it seems to be easily affected by conditions of preservation. In our charcoal material of *Podocarpoxydon McGeei*, for example, a few rather badly crushed fragments still showed the character of the pitting very well but, save infrequently here and there, no traces of "Bars of Sanio." However, the large number of fossil species already described, many of them beautifully preserved, which entirely lack "Bars of Sanio," together with the evident similarity among these in such characters as extreme microphylls, shallow medullary rays and, somewhat less often, of flattened pitting and traumatic resin canals, all combine to indicate the existence in the Jurassic and early Cretaceous of a rather large group of conifers intermediate in many characters between Abietineae, Cupressineae and Podocarpineae on the one hand and Araucarineae on the other, but generally inclining toward the latter.

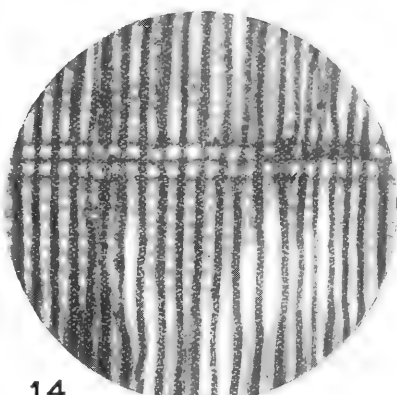
* Jeffrey, E. C., *Araucariopitys*, a new genus of Araucarians, *Bot. Gaz.*, xliv, 435-444, 1907.

† Sinnott, E. W., *Paracedroxylon*, a new type of Araucarian wood, *Rhodora*, xi, 165-173, 1909.

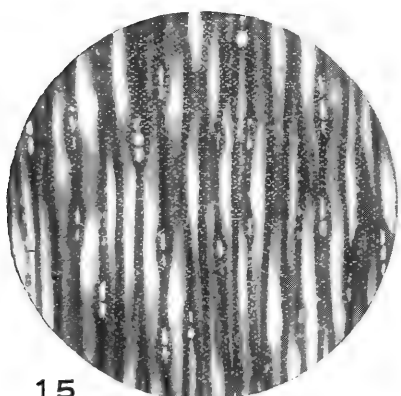
FIGS. 13-18.



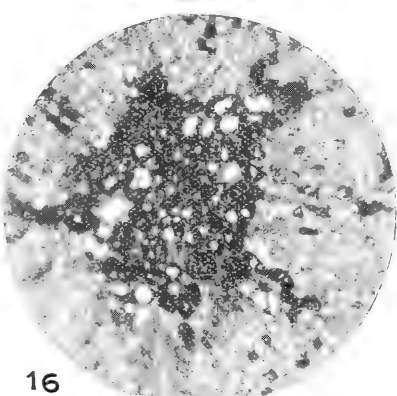
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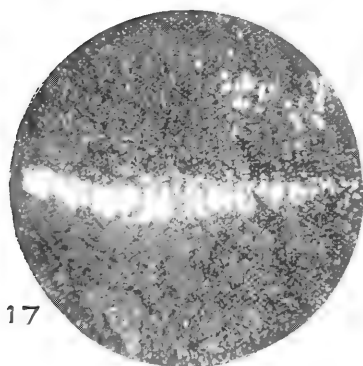
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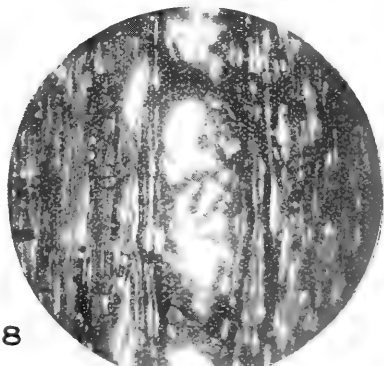
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FIGS. 13-18. *Paracupressinoxylon potomacense*, n. sp.

To this general group, at least, whatever we may believe its affinities to have been, our fossil evidently belongs. In the shallow and thin-walled rays, the scarcity of flattened pitting in the tracheids and the occurrence of traumatic resin canals, it resembles *Brachyoxylon* and *Paracedroxylon*, but these genera like almost all related types entirely lack wood parenchyma, which we have shown to be abundant in our material. Miss Holden, however, has recently proposed the genus *Paracupressinoxylon* to include those woods which resemble true *Cupressinoxyla* in the possession of wood parenchyma but are believed to be really araucarian in affinity, from the absence of "Bars of Sanio." It is under this genus, then, that our fossil should evidently find its place.

Miss Holden describes two species. One of these, *P. cedroides*, from the Jurassic of Yorkshire, possesses traumatic resin canals, as does our wood, but differs in the structure of its rays which are thick-walled and pitted. The other species, *P. cupressoides*, from the same locality and horizon, and also apparently from the Raritan Cretaceous of New Jersey, agrees with our type in having thin-walled rays; but traumatic resin canals were not found and its other characters, particularly those of the lateral ray pits, are too vaguely described to establish its identity with our fossil. The structure of other *Cupressinoxylon*-like fragments from the same New Jersey locality is very briefly described by Miss Holden and with some of these it is possible that our fossil may be identical. She has proposed no other specific names, however. There is also the possibility that our species is *Cupressinoxylon pulchellum* Knowlton from a Potomac locality between Petersburg and City Point, Va., a type which he mentions as possessing very narrow tracheids; but in this case, too, the description is not definite enough to make identity at all certain. As before remarked, Knowlton's sections are not available for comparison. No other course has seemed feasible than to describe our fossil as new.

Correlation with Impressions.

With what leaf and stem impressions these two fossil woods should be correlated we can not be certain, since no leaf-bearing twigs with structure preserved could be obtained. Associated with the lignites and charcoals, however, were found impressions of *Nageiopsis*, *Arthrotaxopsis*, *Brachyphyllum*, *Sphenolepis* and "Sequoia" (Geinitzia). The wood of *Brachyphyllum* (*Brachyoxylon* of Hollick and Jeffrey) has been identified, and bears no resemblance to either of our fossils. Hollick and Jeffrey (l. c.) have likewise described the wood of one of the "Sequoias" of the Raritan formation of

New Jersey, which is not the same as, but nevertheless closely resembles, the one found in the Potomac beds at Washington. It is also different from either of our fossils. The "Sequoia" (Geinitzia) form, moreover, is rare in the deposits, as is also Sphenolepis. There remain only Nageiopsis and Arthrotaxopsis to be considered.

Of these two genera, both of which are abundant, Nageiopsis closely resembles certain of the living broad-leaved Podocarpaceae and has always been regarded as belonging to this family. The fact that one of the wood types associated with it bears anatomical evidence of membership in the same group makes very reasonable the conclusion that *Podocarpoxylon McGeei* is indeed the wood of a species of Nageiopsis.

If this is the case, a relationship is at once suggested between Arthrotaxopsis and *Paracupressinoxylon potomacense*. A study of the internal and external structure of related types renders this conclusion even more probable. Arthrotaxopsis belongs to the large group of Mesozoic conifers which includes Brachyphyllum, Geinitzia, Thuyites, Sphenolepis, Widdringtonites and other similar types. It is perhaps most closely related to the last two genera mentioned. A study by Hollick and Jeffrey (l. c.) of the internal structure of specimens referred to certain of these genera indicates that Brachyphyllum, Geinitzia, Widdringtonites and a species formerly included under Frenelopsis (but placed by them in a new genus, Raritanian) are araucarian rather than cupressineous in their affinities. Since, as we have already shown, evidence from internal structure favors the relationship between *Paracupressinoxylon potomacense* and the wood of these microphyllous conifers, the conclusion is highly probable that in this fossil we possess the wood of one or more species of Arthrotaxopsis. This genus is, therefore, to be added to the increasing array of small-leaved coniferous Mesozoic fossils which are presumably araucarians in disguise.

Much is to be said in favor of the general contention that a large flora both of podocarps and small-leaved araucarians existed in Jurassic and Cretaceous times, but in the present state of our knowledge such a view can not yet be regarded as definitely established. If the wholesale reference of small-leaved impressions and of Cupressinoxyla to the Araucarineae is correct, it renders rather improbable the existence of a very extensive flora of true Cupressineae in the Mesozoic, and favors the view that this group was rather late in making its appearance.

Summary.

1. The present paper records a study of certain lignites and charcoals from the Patuxent horizon of the Potomac forma-

tion. These were found to belong to two types, both coniferous.

2. The first is characterized by wide tracheids with opposite pitting, "bars of Sanio" and few and large pits next the rays; wood parenchyma; and thin-walled, frequently biseriate rays which are often extremely high. It is regarded as a *Podocarpoxylon*, identical with *Cupressinoxylon McGeei* Knowlton, and is accordingly treated as *Podocarpoxylon McGeei* (Knowlton) n. comb. It is believed to represent the wood of a species of *Nageiopsis* and to have close affinities with the *Podocarpineae*.

3. The second type is characterized by narrow tracheids with small, unflattened pitting, no "bars of Sanio," and few pits next the ray cells; wood parenchyma; thin-walled, very shallow rays; and well-developed traumatic resin canals. It is treated as *Paracupressinoxylon potomacense* n. sp., and is believed to represent the wood of a species of *Arthretaxopsis* and to belong to that group of small-leaved Mesozoic conifers which are preponderantly araucarian in their affinities.

This investigation was carried on in part at the Bussey Institution of Harvard University and in part at the Bureau of Plant Industry, U. S. Department of Agriculture.

Connecticut Agricultural College, Storrs, Conn.
University of Michigan.

EXPLANATION OF FIGURES.

PODOCARPOXYLON MCGEEI (Knowlton) n. comb. Pp. 281, 283.

- FIG. 1. Transverse section, showing annual rings.
- FIG. 2. Transverse section, showing wood parenchyma cells filled with resin, and distinctly biseriate medullary rays.
- FIG. 3. Tangential section, showing extremely tall medullary rays.
- FIG. 4. Tangential section, showing partially biseriate rays and especially the resin-filled condition of certain of the ray cells.
- FIG. 5. Radial section, showing clearly the so-called "bars of Sanio" and the transition from opposite pitting to a single row of pits in the same tracheid.
- FIG. 6. Radial section, showing tracheids with a double row of pits, which are usually opposite but in a few cases alternate.
- FIG. 7. Radial section, showing "bars of Sanio" between mutually flattened pits, the variation in size of pits in the same tracheid, and also a longitudinal view of a resiniferous wood parenchyma cell.
- FIG. 8. Radial section, showing pitting of the tracheids.
- FIG. 9. Radial section, showing bordered pits between medullary rays and tracheids, and the highly resiniferous nature of the alternate rows of ray cells.
- FIG. 10. Radial section, showing variation in the pitting between tracheids and ray cells.

PARACUPRESSINOXYLON POTOMACENSE n. sp. P. 289.

- FIG. 11. Transverse section, showing annual rings.
- FIG. 12. Transverse section, showing uniseriate medullary rays and numerous resiniferous wood parenchyma cells.

- FIG. 13. Radial section, showing the shallow medullary rays.
 FIG. 14. Radial section, showing the usually distant bordered tracheid pits, in a single row, and the pits between ray and tracheids.
 FIG. 15. Tangential section, showing in cross section the very low medullary rays and the pits of the radial walls of the tracheids.
 FIG. 16. Transverse section of the pith.
 FIG. 17. Transverse section, showing a row of traumatic resin canals.
 FIG. 18. Radial section, showing parenchyma and tyloses of a traumatic resin canal.

SCIENTIFIC INTELLIGENCE.

I. CHEMISTRY AND PHYSICS.

1. *The Density of Lead from Radioactive Minerals.*—THEODORE W. RICHARDS and CHARLES WADSWORTH, 3RD, have studied this matter on account of the startling differences that have been observed by several investigators in the atomic weight of lead from radioactive sources; for these differences suggest that other properties may vary in different specimens, and the comparison of these may be of service in tracing the true causes of the differences in atomic weights. The authors observe that the phenomena are of interest whether or not the plausible hypothesis of Soddy and Fajans concerning the "isotopes" is accepted. They describe a special stoppered pycnometer that was used for the work, and give details of the very careful methods that were employed for purifying the samples of lead. Two samples of ordinary lead and one of radioactive lead of Australian origin were used. The latter was taken in two states of purification. The following average results were obtained at 19.94° C.:

Density of ordinary lead	11.337
Density of radioactive lead	11.288
Density of same, further fractionated..	11.289

The density of radioactive lead is thus found to be 0.049, or 0.43 per cent lower than that of ordinary lead, a very striking difference. It is interesting to notice that the atomic volume of the Australian radioactive lead is practically the same as that of ordinary lead, for the atomic weights, as they have been determined, are respectively 206.3 and 207.3, so that the atomic volumes (206.3/11.288 and 207.2/11.337) are 18.276 and 18.277. Of course, no one knows as yet what proportion of impurity exists in the radioactive sample, which doubtless contains some ordinary lead, but if the atomic weight of the pure "isotope" is really 206, this sample must have consisted chiefly of the isotope. On the other hand, it is possible that the theory is incomplete and that the

lowering of the atomic weight and density is due to the admixture of a smaller amount of a substance with a lower atomic weight.—*Jour. Amer. Chem. Soc.*, xxxviii, 169. H. L. W.

2. *Representative Procedures in Quantitative Analysis*, by FRANK AUSTIN GOOCH. 8vo, pp. 262. New York, 1916 (John Wiley & Sons, Inc. Price \$2 net).—The presentation of a course of instruction by an author of such eminence in researches in this subject is naturally of the highest interest to teachers of analytical chemistry, and an examination of the book will show it to be an important and valuable work. Scattered through the book are numerous "experimental processes," or exercises for practice, including the analysis of brass, of limestone, of silicates for alkali elements, and some 40 or 50 determinations of metals and "ions" (meaning acidic elements or groups). These processes are very clearly discussed in relation to their essential features, underlying principles, and varied applications. In addition to the exercises for practice a good deal of valuable information is given in regard to other methods of determination, among which, of course, the methods that have been devised or studied by the author and his students are prominent. Since the scope of the book is limited, many important methods are not described; for instance, for the determination of carbon, hydrogen and nitrogen in organic substances the student is referred to other books. The separations of metals and acid radicals from one another are discussed only incidentally in connection with the determinations. The treatment of the subject of volumetric analysis, particularly of the iodometric processes, is very elaborate and excellent. The author states that a large amount of space has been devoted to iodometric processes both on account of the beauty and accuracy of these methods, constantly growing in recognition, and because the treatment in the more elementary text-books is usually scanty. The book seems to be very well adapted to the purpose of inspiring the student with a desire to attain high accuracy, and giving him at the same time a good knowledge of the important principles and facts of the science. In the opinion of the reviewer the methods of weighing by the use of long swings of the balance are less satisfactory than those where short swings are employed.

H. L. W.

3. *The Molecular Volumes of Liquid Chemical Compounds*, by GERVAISE LEBAS. 8vo, pp. 275. London, 1915 (Longmans, Green and Co. Price \$2.25 net).—This is the seventh to appear of the important series of monographs on inorganic and physical chemistry, edited by Professor Alexander Findlay, and intended for the use of advanced students. The present volume deals with an application of the theory of molecular volumes from the point of view of Kopp to a study of the constitutions of organic compounds chiefly. The author has taken up this line of work after a period of about 25 years in which little or no advance has been made. A very extensive study of molecular volumes has been carried out and important results have been obtained, particularly

in showing that the additive values used by Kopp for carbon and hydrogen were incorrect, and in pointing out the effects of various structures upon the volumes of the atoms. The conclusion has been reached that no physical property is so well adapted to elucidate the ring structure of a compound as the molecular volume, so that it is to be hoped that this will henceforward take its legitimate place as an instrument of research. The book is of much interest to both physical and organic chemists. H. L. W.

4. *A Handbook of Colloidal Chemistry*; by WOLFGANG OSTWALD. 8vo, pp. 278. Philadelphia, 1915 (P. Blakiston's Son & Co. Price \$3 net).—The first edition of this book in English has been translated in a very satisfactory manner from the third German edition by Dr. Martin Fischer with the assistance of Dr. Ralph E. Oesper and Dr. Louis Berman. As a frontispiece there is an interesting portrait of the English chemist Thomas Graham, who first distinguished colloids as a class of substances and who coined the word. The important recent growth of this branch of chemistry is well shown in this book, and the subject is treated in a very full and satisfactory manner. The work cannot fail to be interesting and useful to all classes of chemists and physicists. H. L. W.

5. *The Critical Temperature of Mercury*.—J. Koenigsberger concluded from his experimental work that the critical temperature of mercury is about 1270°C . Since this investigation has been criticized adversely as giving too low a value, the problem has been taken up anew by JULIE BENDER at the suggestion of Koenigsberger. The general method consisted in determining the vapor pressure of mercury at high temperatures while the total volume of the liquid and vapor was kept constant. The mercury was sealed in capillary tubes made of the purest fused quartz and the temperatures were determined by the aid of a thermopile. An estimate of the critical temperature was obtained in two different ways.

The first plan was to observe the changes in volume (or length) of the thread of liquid for different "fillings" and for various temperatures up to 1400°C . By a "filling" is meant the ratio of the volume of the liquid phase present to the total volume of the inside of the capillary cylinder. When fillings are plotted as abscissas and the corresponding temperatures as ordinates one curve is obtained for each initial filling, and all of the curves possess the general characteristics of the so-called Bragg ionization curves. That is, with rising temperature the filling first increases, then passes through a point of inflection to a maximum, and finally decreases. The most significant properties of these curves are that they become practically straight lines above their maxima—up to the highest temperature (1400°C .) at which observations with silica tubes could be made with sufficient accuracy—and that the extensions of the rectilinear portions converge toward one another so as to include between their extreme intercepts on the axis of ordinates the interval $1650^{\circ}\text{--}1700^{\circ}\text{C}$.

This means that the critical temperature lies within the range just given. The investigator observed liquid mercury at a temperature of 1500°C ., so that the critical value 1270°C . published by Koenigsberger is undoubtedly too low.

The second plan involved the determination of the densities of the liquid and vapor states. The experimental procedure consisted in starting with small fillings (0.06 to 0.13) and noting the temperature at the precise instant when the liquid phase vanished. The value of the vapor density could be obtained at once from the relative volumes of the filling and capillary. The density of the liquid mercury at a chosen temperature could be calculated by applying corrections for the amount of mercury vaporized to the data found by the first method employed. When the points are plotted in rectangular coördinates with densities and temperatures as abscissas and ordinates, respectively, a smooth locus is generated which has the general appearance of a parabola whose axis makes an angle of about 100° with the positive direction of the axis of density. The vapor density segment apparently leaves the axis of ordinates at about 700°C . and curves away from this line until, at the experimental limit 1400°C ., the density is approximately 1.6 . The liquid density segment, on the other hand, begins with the intercept 13.6 at 0°C . and bends toward the temperature axis, the numerical value of the density being about 7.8 at 1400°C . By dotting in the region of the vertex of the curve the critical temperature is found to be roughly 1650°C . which confirms the result obtained from the first family of curves. By assuming the validity of Boyle's law the author of the original paper deduces the value 1180 atmospheres for the vapor pressure of mercury at 1400°C .

In conclusion Bender calls attention to the following interesting phenomenon which was observed between 1200° and 1300°C . At 1200°C . the vapor, which had appeared to be perfectly transparent and colorless at lower temperatures, began to show a faint blue luminosity whose intensity increased as the temperature was raised. For fillings less than 0.30 this could not be observed, whereas it became sensible at 0.30 and above 0.40 at temperatures of about 1300°C . and 1270°C . respectively.—*Physik. Zeitschr.* No 13/14, July, 1915, p. 246. H. S. U.

6. *The Thermal Conductivity of Neon*.—According to the kinetic theory of gases the specific thermal conductivity (k) is connected with the coefficient of viscosity (η) and the specific heat at constant volume (c_v) by the equation $k = f\eta c_v$. For monatomic gases f should have the value $5/2$, which agrees very well with the experimental data 2.501 and 2.507 as obtained by Schwarze for argon and helium respectively. For polyatomic gases various theoretical expressions for f have been deduced but none agrees with the observed facts. To subject the matter to further test ERICH BANNAWITZ has determined very carefully the value of k for neon. Since Rankine found, for neon at 10.1°C ., $\eta = 3.036 \times 10^{-4}$ and since c_v can be calculated from the theoret-

ical relation $c_f/c_v = 5/3$, it was only necessary to determine k experimentally in order to evaluate f . Bannawitz found the temperature coefficient γ , in the equation $k_t = k_0(1 + \gamma t)$, to equal 0.00259 and also $k_0 = 0.0001091$. Consequently, for neon at 10.1°C ., $k = 0.00011195$. Hence $f = 2.501$, which is in perfect experimental agreement with the theoretical value $5/2$.—*Ann. d. Physik*, vol. xlviii, pp. 577–592, November, 1915. H. S. U.

7. *Relativity and the Electron Theory*; by E. CUNNINGHAM. Pp. vii, 96. London, 1915 (Longmans, Green and Co.).—"This monograph is an attempt to set out as clearly and simply as possible the relation of the Principle of Relativity to the generally accepted Electron Theory, showing at what points the former is the natural and necessary complement of the latter." In order to make the text useful to the general reader and more especially to the experimental physicist, the mathematical analysis has been omitted or placed in the background as far as possible, and no attempt has been made to describe at length such consequences of the Principle of Relativity as would be for the most part beyond the reach of experimental investigation. The experiments leading up to the enunciation of the Principle are discussed in a very lucid and interesting manner, and the entire text is admirably designed to meet the needs of the readers to whom it is especially addressed. H. S. U.

8. *The Telephone and Telephone Exchanges*; by J. E. KINGSBURY. Pp. x, 558, with 170 figures. London, 1915 (Longmans, Green and Co.).—In this book the inventions and developments in the telephone field are discussed in such a manner as to constitute a fairly complete history of the industry. The circumstances leading up to the principal inventions, the developments resulting from them, and the influences bearing on them are considered in detail. The subject of exchange service necessarily involves the technical, commercial, and political aspects of the subject. Many quotations from original sources are incorporated. For example, the evidence given by Bell in the various law suits concerning his inventions has been appropriately interwoven in the text. In some instances the author has been able to obtain and present material which was heretofore inaccessible to the public. Thus, authoritative information relating to the most important developments in switchboards, cables, and exchange service generally has been derived first hand from the original reports of the committees and conferences of experts of the Western Electric Company and of other American Companies. Interest in the subject is enlivened by quotations from letters and personal conversations between noted scientists. The author's style is clear and pleasing, the line diagrams and half-tone figures are excellent, and the text is unquestionably a valuable contribution to the history of the subject. H. S. U.

9. *A Course of Modern Analysis*; by E. T. WHITTAKER and G. N. WATSON. Second edition, completely revised. Pp. 560. Cambridge, 1915 (University Press).—The text is divided into

two parts which deal respectively with the processes of analysis (223 pages) and with the transcendental functions (312 pages). In order to give a general idea of the scope of the course and to suggest the kinds of theorems which are discussed, the titles of the chapters will now be quoted.

"Part I. I Complex Numbers. II The Theory of Convergence. III Continuous Functions and Uniform Convergence. IV The Theory of Riemann Integration. V The fundamental properties of Analytic Functions; Taylor's, Laurent's, and Liouville's Theorems. VI The Theory of Residues; application to the evaluation of Definite Integrals. VII The expansion of functions in Infinite Series. VIII Asymptotic Expansions and Summable Series. IX Fourier Series. X Linear Differential Equations. XI Integral Equations."

"Part II. XII The Gamma Function. XIII The Zeta Function of Riemann. XIV The Hypergeometric Function. XV Legendre Functions. XVI The Confluent Hypergeometric Function. XVII Bessel Functions. XVIII The Equations of Mathematical Physics. XIX Mathieu Functions. XX Elliptic Functions. General theorems and the Weierstrassian Functions. XXI The Theta Functions. XXII The Jacobian Elliptic Functions."

As may be inferred from the above titles, the book is of a relatively advanced character. The analysis in chapter X is mainly theoretical and consists, for the most part, in existence theorems. Physicists will be especially interested in chapter XVIII. Numerous illustrative examples for solution by the reader are scattered through the text and lists of miscellaneous problems are appended to the chapters. At the ends of the chapters bibliographical references may also be found. The volume closes with author and subject indexes. The decimal system of paragraphing is used throughout and every precaution seems to have been taken to minimize the number of typographical errors. H. S. U.

10. *Edinburgh Mathematical Tracts*; edited by E. T. WHITTAKER. London, 1915 (G. Bell and Sons).—No. 1. *Descriptive Geometry and Photogrammetry*; by E. LINDSAY INCE. Pp. viii, 79. No. 2. *Interpolation and Numerical Integration*; by DAVID GIBB. Pp. viii, 90. No. 3. *Relativity*; by A. W. CONWAY. Pp. 43. No. 4. *Fourier's Analysis and Periodogram Analysis*; by G. A. CARSE and G. SHEARER. Pp. viii, 66. No. 5. *Spherical Triangles*; by HERBERT BELL. Pp. viii, 66. No. 6. *Automorphic Functions*; by LESTER R. FORD. Pp. viii, 96.

The first, second, fourth, and fifth Tracts present short courses for the mathematical laboratory, the chief object of which is to give the non-technical student much needed practice in graphical construction and numerical computation. Tract No. 3 contains the material of four lectures delivered before the Edinburgh Mathematical Colloquium. The subject is developed in the historical order and is brought down to the stage in which it was left by Minkowski. The point of view is primarily mathematical,

scalar notation being used throughout. Tract No. 6 constitutes a short course in the special field with which it deals. It owes its origin to a series of lectures given to the Mathematical Research Class during the Spring Term of 1915.

H. S. U.

II. GEOLOGY.

1. *The Pebble Phosphates of Florida*; by E. H. SELLARDS. Florida State Geol. Surv., 7th Ann. Rep. 1915; pp. 29-116, 52 figures.—The importance of the phosphate deposits of Florida has long been realized and some knowledge of the geology of the hard-rock phosphates has been available but, until the appearance in September, 1915, of Dr. Sellards' paper, very little had been known of the commercially more important pebble-phosphates.

To give a clear conception of the origin of the pebble-phosphates Dr. Sellards describes the geology of Southern Florida with particular emphasis on the late geologic history of the region. The Tertiary stratigraphy is discussed in detail and the fossils found are illustrated in a number of well-prepared plates. It is pointed out that the hard-rock phosphate occurs chiefly as pebble in marl of the Alum Bluff formation of late Oligocene age. Its deposition was followed by an emergence and a period of erosion. Another submergence in late Miocene or probably early Pliocene allowed the sea to advance across the irregularly eroded surface of phosphatic marl and there was formed first of all a basal conglomerate, the pebbles of which are chiefly phosphate. These deposits form part of the Bone Valley formation and the basal conglomerate constitutes in places the workable phosphate deposits.

It is pointed out that the pebble-phosphate deposits vary in thickness and continuity and the explanation is offered that this is due to the irregularity of the erosion surface upon which the pebbles were deposited and to the constantly changing depth of water and force of wave action of the advancing sea. The variation in phosphate content of the deposits may be due to irregular sorting action of water, to varying phosphate content of the supply pebble, and to a secondary enrichment of the deposits, more complete in some places than in others.

The origin of the deposits as outlined by Dr. Sellards appears to explain very satisfactorily the many perplexing problems that these deposits present. The variation in continuity, thickness and phosphate content may readily be understood by the hypothesis advanced and should be of help in the mining of the deposits, although no criteria are advanced which would help exploration for more phosphate. The recognition of secondary enrichment in the phosphate deposits is an interesting contribution. The value of this contribution might be enhanced if it could be determined what controls the degree and location of the secondary enrichment.

A. M. BATEMAN.

2. *The Phosphate Deposits of Florida*; by G. C. MATSON. U. S. G. S., Bull. 604, 1915, pp. 99, 17 plates and geologic map.—Shortly after the "Pebble Phosphates of Florida" by E. H. Sel-lards made its appearance, another paper on Florida phosphate deposits, by G. C. Matson, was received. This paper is a comprehensive treatise of the different kinds of phosphate deposits of Florida, while the former deals with the pebble-phosphates.

The geology of Florida is described in considerable detail and correlations made between formations in different parts of the state. Detailed descriptions and discussions of the mode of occurrence of the phosphate deposits of the individual districts is given. The hard-rock, pebble-phosphates and river-pebble phosphates, are all described and discussed and a review of the literature is made concerning the origin of these different types of phosphate deposits.

The rock-phosphates occur in the Vicksburg ground of lower Oligocene age and in the Bluff Alum formation of upper Oligocene Age. They consist of boulders and pebbles enclosed in a matrix of soft phosphate and clay. Those of the Vicksburg group have in part been formed in place by alteration of calcium carbonate to calcium phosphate under the influence of solutions bearing phosphoric acid, and in part by the erosion and redeposition of pre-existing phosphate. For the origin of the phosphoric acid of the Vicksburg group three theories are considered: that of original phosphate in the limestone, phosphate derived from organic matter and phosphate derived from the overlying Alum Bluff formation. The latter is considered the most probable. The rock-phosphate of the Alum Bluff formation is believed to be marine phosphate.

The land-pebble phosphate of the Bone Valley formation is thought to have been derived from the underlying formation by erosion and deposited as a phosphate conglomerate during the late Miocene or early Pleiocene incursion of the sea. The variation in size and phosphoric acid content of the deposits is considered to be due to local concentration or dissipation of the pebbles in the process of water sorting.

The river-pebble phosphates are considered to be of fluvial origin and derived by rivers of Pleistocene and Recent age working over the Bone Valley formation.

This paper presents the most complete data we have concerning the occurrence and origin of the Florida phosphate deposits and the theories of origin are of wide application. Views held by previous writers have been reviewed, and a complete bibliography of Florida phosphates lends additional value to the report.

A. M. BATEMAN.

3. *A Correction*; by F. BASCOM (*Communicated*).—Shortly after the publication of a paper on the Petrographic Province of Neponset Valley, Massachusetts,* Dr. Whitman Cross very kindly

* Bascom, F., Journal of the Academy of Natural Sciences of Philadelphia, Second Series, vol. xv, pp. 131-161, 1912.

called the writer's attention to an error in the calculation of the norm of "neponsetose," * namely, the calculation of hypersthene with nephelite. Since the former of these constituents by taking up silica increases the amount of nephelite, this error led to placing the rock in the wrong order (II. 6.2.5.). The publication of the correction has been delayed in order to secure a new and complete analysis of the freshest material obtainable of the andesitic lava.

Specimens from five localities, most kindly collected for the writer by Prof. W. O. Crosby, were sectioned and field observations, macroscopic, and microscopic study were utilized in selecting the material from which the following analysis has been made and the following norm calculated. The rock falls in Class II, order 5 (6), rang (1) 2, sub-rang "5.

Analysis of Neponsetose. †			
			Norm
SiO ₂	50.09	Orthoclase	6.67
Al ₂ O ₃	15.84	Albite	47.68
Fe ₂ O ₃	7.44	Anorthite	6.12
FeO	3.80	Nephelite	8.52
MgO	4.98	Diopside	7.34
CaO	3.54	Olivine	6.80
Na ₂ O	7.50	Magnetite	7.42
K ₂ O	1.10	Ilmenite	3.19
H ₂ O ±	3.67	Hematite	2.40
CO ₂	0.34	Apatite67
TiO ₂	1.70	H ₂ O ±	3.67
P ₂ O ₅	0.32	CO ₂34
MnO	trace		
	<hr/>		<hr/>
	100.32		100.30

II. 5(6). (1)2. "5.

4. *Cambrian Trilobites*; by CHARLES D. WALCOTT. Smithsonian. Misc. Coll., vol. 64, No. 3, 1916, pp. 157-259, pls. 24-38.—Here are described 68 forms of trilobites, of which 49 are new, the new genera being *Menomonina* (*M. calymenoides* has 42 thoracic segments), *Millardia*, *Dresbachia*, *Norwoodia*, *Saratogia*, *Vanuxemella*, and *Hanburia*. The first four of the above genera are of the order Proparia. The genus *Crepicephalus* now has 17 species. Besides the paleontological value of the paper, more stratigraphic evidence is now at hand for the correlation of Middle and Upper Cambrian formations in North America. The Weeks formation of the Cordilleran region is transferred from the Middle to the Upper Cambrian and the Conasauga formation of Alabama, while in the main Upper Cambrian, also seems to have Middle Cambrian trilobites.

C. S.

* Op. cit., p. 153.

† Specimen from Delhi Street, Mattapan, Suffolk County, Mass. Wm. T. Hall, Analyst, Laboratory of Analytical Chemistry, Boston, Mass.

5. *An Introduction to the Geology of Dayton (Ohio) and vicinity, with special reference to the Gravel Ridge Area south of the City, including Hills and Dales and Moraine Park*; by AUG. F. FÖRSTER. Pp. 210, with many illustrations and maps. Dayton, 1915.—This well prepared and beautifully illustrated book was written by the author to simulate interest in nature studies and especially in the surficial and glacial geology in the vicinity of Dayton, Ohio. It is a labor of love, made possible through the kindness of Mr. E. A. Deeds. Attention is called to it here in the hope that others may read it and be stimulated to prepare something of the same sort for other large communities.

C. S.

6. *Studies in Edrioasteroidea, I-IX*: by F. A. BATHER. Pp. 136, 13 pls., 191.—Doctor Bather of the British Museum of Natural History brings together in this very valuable work nine studies which he has published since 1898. They relate, on the one hand, to the detailed structure of *Dinocystis*, *Edrioaster*, *Lebetodiscus*, *Steganoblastus* and *Purgocystis*, and, on the other, to the morphology and bionomics of the Edrioasteroidea and their genetic relations to other echinoderms, and more particularly the starfishes. To these reprints he adds a few corrections, a preface, and an index: the whole may be had of the author for ten shillings. The work should be in the library of all who are interested in the Echinodermata.

C. S.

7. *Handbuch der Regionalen Geologie*.—This great undertaking—the geology of the world—begun in 1910, has now appeared in eighteen numbers. It was intended to complete the series in a few years, but evidently it will be many years more before the work is finally ended. So far the regions described are: (1) Denmark (by Ussing), (2) Iceland (Pjeturss), (3) Philippines (W. D. Smith), (4) Middle Atlantic volcanic islands (Gagel), (5) New Zealand (Marshall), (6) Madagascar (Lemoine), (7) Spain (Douvillé), (8) Persia (Stahl), (9) Oceania (Marshall), (10) Armenia (Oswald), (11) United States (Blackwelder), (12) Netherlands (Mohlengraaff), (13) Norway, Sweden and Finland (Högbom), (14) West Africa (Lemoine-Parkinson), (15) Antarctica (Nordenskjöld), (16) Balkans of Austria-Hungary (Schubert), (17) Syria, Arabia and Mesopotamia (Planckenhorn).

C. S.

8. *Geologia Elementar, preparada com referencia especial aos Estudantes Brasileiros e á Geologia do Brazil*; by JOHN C. BRANNER. Second edition, 1915, pp. 396, 174 text figs.—Professor Branner has long been deeply interested in the geology of Brazil, and he here presents a second edition of his text-book in Portuguese of Elementary Geology, with special reference to Brazil. Dynamical Geology occupies about 200 pages, Structural Geology 70 pages, and Historical Geology 100 pages. There are plates of Silurian, Devonian, Pennsylvanian, Permian, Jurassic, Cretaceous and Tertiary fossils native to Brazil.

C. S.

III. MISCELLANEOUS SCIENTIFIC INTELLIGENCE.

1. *Report of the Secretary of the Smithsonian Institution, CHARLES D. WALCOTT, for the year ending June 30, 1915.* Pp. iii, 110. Washington, 1915.—The activities of the Smithsonian Institution now extend into many and diverse fields, with the National Museum, the Zoological park, the Astrophysical Laboratory, its Library with its extended publications and the International Exchanges and others: the year's work in these is concisely summarized in the report of the Secretary. In addition to the departments mentioned, many lines of scientific exploration and investigation have been carried forward. These include Dr. Walcott's own work in the Rocky Mountains of Canada and Montana; that of Dr. Ulrich and Bassler in Central Tennessee; of Mr. Springer on the fossil echinoderms of Western New York; etc. It is noted that Mr. C. W. Gilmore of the National Museum, in his investigation of the fossil vertebrate remains of the Judith River in Montana, has discovered remains of a fossil bird related to *Hesperornis*, coming from practically the same locality as Marsh's species *Coniornis*. These bird remains are shown to occur in the upper part of the Claggett formation. Collections in natural history have also been made by Mr. Raven on Borneo and Celebes; also botanical explorations in South America by Dr. J. N. Rose. The work of the National Museum has also been carried forward with much activity, and upwards of 300,000 specimens added to the collections. Further, the Bureau of American Ethnology has done extensive field work and various publications have resulted. After investigating the Indian mounds in Kansas and Nebraska, Mr. Fowke has concluded that the mounds, instead of having an antiquity of many thousands of years, cannot have existed as long as ten centuries.

The general work of the Institution has been prosecuted, as usual, in the line of publication, the volumes and pamphlets distributed numbering 132,000; on the other hand, the operations of the International Exchange Service have been very seriously curtailed in consequence of the European war. Following the general report of the Secretary are a series of Appendixes by the officers in charge of the different departments. These include, among others, the Report of the National Museum by Dr. Rathbun, and that of Dr. Abbot on the Astrophysical Observatory. Some of the results of the latter are here noted.

One of the principal researches by the Astrophysical Observatory during the past year was the continuation of observations as to the intensity of solar radiation at various altitudes, with a view to definitely determine the value of the solar constant of radiation. By means of sounding balloons, to which were attached automatic recording pyrheliometers, successful records were secured up to a height of 25,000 meters or about 15 miles, where the barometric pressure is only one twenty-fifth that at sea level. Director Abbot, in his report and in a special publication (*Smithsonian Miscellaneous Collections*, Vol. 65, No. 4, June 19, 1915), reviews the observations in solar radia-

tion made at various altitudes from sea level up to the highest practicable mountain peak (Mount Whitney), thence in a balloon as high as man could live, thence to a height of 15 miles, and concludes that the solar constant of radiation is 1.93 calories per square centimeter per minute. Dr. Abbot discusses also the interesting fact that considerable fluctuations of the "solar-constant" values occur from day to day ranging over nearly 10 per cent between the extreme limits, 1.81 and 1.99 calories. In 1913 the radiation of the sun was 2.5 per cent below the mean, and 1 per cent above the mean in 1914. A high average value is said to be indicated for 1915. Dr. Abbot remarks in conclusion: "Short-period fluctuations of solar radiation were large in 1913, but small in 1914. Associated with these quick, irregular fluctuations are found variations of contrast of brightness between the center and edges of the solar disk. Curiously enough, while greater contrast is associated with greater solar radiation and with numerous sun spots in the general march of the sun's activity, lesser contrast is associated with greater solar radiation in the march of the quick, irregular fluctuations of the sun's emission. This paradox points to two causes of solar variation—the long-period changes may probably be caused by changes of the sun's effective temperature attending the march of solar activity; the quick fluctuations may be ascribed to changes of the transparency of the outer solar envelopes."

2. *Memorial Volume of the Transcontinental Excursion of 1912 of the American Geographical Society of New York.* Pp. xi, 407; with numerous plates, maps and other illustrations. New York, 1915 (Published by the Society).—This handsome volume forms a fitting record of the remarkable double trip across the United States accomplished in 1912 by the International Geographers under the auspices of the American Geographical Society. The general idea for this excursion first originated with Professor Davis in 1908, and was later developed by him; in the leading paper of the volume (pp. 2-7) he gives an account of the growth of the plan from the beginning and the way in which it was carried out under his able supervision, as director. The history of the trip is given by Professor Albert P. Brigham (pp. 9-45). The important occasion of the excursion was the celebration of the sixtieth anniversary of the founding of the American Geographical Society of New York and the completion of its new building on upper Broadway. Forty-three European geographers from thirteen different countries were present, and with their American associates carried on a journey beginning on August 22 and extending over two months to the Pacific coast and back. The important object aimed at was to give each person present as good an opportunity as possible to become acquainted with the most interesting features of the United States, and the itinerary given by Dr. Brigham, with the special notes and maps accompanying it, show how thoroughly the plan was carried out. Portraits of many of the delegates accompany this paper by Dr. Brigham. The remainder of the volume, upwards of 300 pages, is occupied by a series of twenty-four interesting papers by the foreign delegates, nearly all of which are published here for the first time. These papers are in part in French and German and contain valuable contributions to the geography of the regions visited as seen through foreign eyes. They are liberally illustrated and some of the most interesting

concern the Yellowstone Park and its geysers, the Grand Canyon and the Sierra Nevada. The concluding paper discusses the surface of Central Norway.

3. *Publications of the Carnegie Institution of Washington.*—Recent publications of the Carnegie Institution are noted in the following list (continued from p. 523, November, 1915):—

No. 159. The Mosquitoes of North and Central America and the West Indies ; by L. O. HOWARD, H. G. DYAR and FREDERICK KNAB. Volume Three. Systematic Description (in two parts). Part I. Pp. vi, 523.

No. 189. A Concordance to the Poems of Edmund Spenser ; compiled and edited by CHARLES GROSVENOR OSGOOD. 4to. Pp. xiii, 997.

No. 206. The Relation of Plants to Tide-Levels: A study of factors affecting the distribution of marine plants ; by DUNCAN S. JOHNSON and HARLAN H. YORK. Pp. 162.

No. 215A. History of Domestic and Foreign Commerce of the United States ; by E. R. JOHNSON, T. W. VAN METRE, G. G. HUEBNER, and D. S. HANCHETT. With an Introductory Note by HENRY W. FARNAM. Vol. I, pp. xv, 363 ; Vols. II, pp. ix, 398.

No. 216. A Comparison of Methods for determining the Respiratory Exchange of Man ; by THORNE M. CARPENTER. Pp. 265, 74 figs.

No. 217. The Vegetation of a Desert Mountain Range as conditioned by Climatic Factors ; by FORREST SHREEVE. Pp. 112 ; 36 pls.

No. 218. The Establishment of Varieties in Coleus by the Selection of Somatic Variations ; by A. B. STOUT. Pp. 80 ; 29 figs., 4 pls.

No. 223. Contributions to Embryology. 4to. Volume III, Nos. 7, 8, 9. Pp. 90.

No. 229. Experiments with the Displacement Interferometer ; by CARL BARUS. Pp. vi, 113 ; 66 figs., 18 tables.

No. 230. Conductivities and Viscosities in pure and in mixed Solvents. Radiometric Measurements of the Ionization Constants of Indicators ; by HARRY C. JONES and collaborators. Pp. vii, 175 ; 21 figs.

No. 231. Energy Transformations during Horizontal Walking ; by FRANCIS G. BENEDICT and HANS MURSCHEHAUSER. Pp. 100 ; 7 figs.

No. 236. The Feebly Inhibited. Nomadism, or the wandering impulse, with special reference to Heredity. Inheritance of Temperament ; by CHARLES B. DAVENPORT. Pp. 158. (Paper No. 24 of the station for Experimental Evolution at Cold Spring Harbor, New York.)

4. *Annual Report of the Superintendent of the United States Coast and Geodetic Survey*, E. LESTER JONES, to the Secretary of Commerce, W. C. REDFIELD, for the fiscal year ended June 30, 1915. Pp. 156, with numerous maps and other illustrations. Washington, 1915.—This report is in two parts :

the first discusses in detail and most convincingly the many and urgent needs of the Bureau in its different lines of work. The second part gives a statement of the field and office work accomplished during the year. A series of large maps (Nos. 3-6) shows the condition of the hydrographic survey of the coasts and their harbors, Atlantic, Gulf, Pacific and Alaskan. These charts show in striking manner the large amount of additional work imperatively called for. In this connection it is satisfactory to note that an increased appropriation has made it possible to place in the field four parties for wire-drag work instead of two (see pp. 225-227, February, 1915).

5. *Publications of the United States Naval Observatory*; J. A. HOOGWERFF, U. S. N., Superintendent. Second Series. Volume IX, part II. Pp. Bvii, B759. Washington, 1915.—Of the four parts making up volume IX, the second part is now issued. It contains the observations made with the nine-inch transit circle, 1903-1908, under the direction of W. S. Eichelberger.

The Annual Report of the Naval Observatory for the fiscal year 1915 (pp. 1-19) has also been recently published.

6. *Publications of the Allegheny Observatory of the University of Pittsburgh*.—The following papers have been recently issued:

Vol. III, No. 19. Tables for parallax factors in right ascension; by FRANK SCHLESINGER; pp. 161-165.

No. 20. Spectrographic observations of λ Tauri, indicating the presence of a third body in the system; by FRANK SCHLESINGER; pp. 167-178.

No. 21. The orbit and spectrum of VV. Orionis; by ZACHEUS DANIEL; pp. 179-188.

OBITUARY.

DR. DANIEL GIRAUD ELLIOT, the distinguished ornithologist and mammalogist, died at his home in New York City on December 22 at the age of eighty years.

SIR JOHN RHYS, the well-known English anthropologist, died on December 17 at the age of seventy-five years.

PROFESSOR JOHAN CHRISTIAN MOBERG, of the University of Lund, Sweden, the distinguished paleontologist and stratigrapher, died on December 30, 1915, at the age of sixty-one years. His scientific work related in the main to the older Paleozoic formations of Sweden.

DR. HEINRICH DEBUS, the veteran chemist, died at Cassel, Germany, on December 9 in the ninety-second year of his age. Though born in Germany he came to England in 1851, and spent most of his productive years in that country, where he was intimately associated with Frankland and others.

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FOURTH SERIES

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[FOURTH SERIES.]

ART. XIX.—*A Universal Switch for Thermoelement Work and Other Potential Measurements*; by WALTER P. WHITE.

THE switch here described is used to simplify the manipulations required in making simultaneous measurements with different electrical instruments, especially thermoelements or other sources of electromotive force. The type is more effective, thermoelectrically, than any other known to me, is more convenient to manipulate, is easier to take apart, inspect, or clean, and has a distinctive advantage in the ease with which it can be constructed. Similar switches have been used in our laboratory for the following purposes, among others: (1) In melting point determinations, to measure the temperature at one or two points in the furnace cavity as well as in the charge, thus permitting a better regulation of the furnace temperature, an allowance for its fluctuations, and a closer estimate of the thermal magnitudes involved;* (2) in work on heat conduction, to avoid certain errors by measuring the temperature at several points instead of one, and to measure both gradient and temperature rate without elaborate duplication of apparatus; (3) in calorimetry, to measure, besides the calorimeter temperature itself, various temperature differences, upon which the corrections depend, or which, though ordinarily not necessary, and hence not likely to be observed unless observing is easy, may be of the highest diagnostic value if unexpected errors appear; (4) in specific heat work, to make measurements upon both furnace and calorimeter; (5) in some other kinds of determinations, to measure electrical energy along with the calorimetric temperatures; (6) in calibrations and comparisons of many sorts, whether of thermoelements, resist-

* Cf. *Melting Point Methods at High Temperatures*, Walter P. White, this Journal, xxviii, 478, 482-88, 1909; Zs. anorg. Chem., lxi, 337, 342-50, 1911.

ances, voltages, or currents, to permit the different measurements to be alternated with a rapidity that greatly increases precision and also to allow necessary or desirable auxiliary measurements to be made in many cases.

For many of these purposes a double potentiometer, or something equivalent, is almost necessary. Such potentiometers are now readily obtainable and at a low cost;* the exchanging switch here described may therefore be said to complete the provision of a satisfactory outfit for all such kinds of work.†

In determinations such as those just mentioned, it is of course often possible to get along with but one electrical measuring instrument, and in many cases a procedure which permits this has been developed, so that the use of more than one seems strange, if not over complicated. This situation, however, may be regarded as the legacy from a régime of crude or restricted apparatus, for as a rule the procedure with only one electrical measuring instrument is obviously and seriously disadvantageous.‡

In mere convenience also, aside from the value of the results, a switch like the present will in a few years more than pay for its installation.

Of course, all these considerations gain in weight as the construction of the switch becomes easier, and it is partly on account of its ease of construction that the present switch has seemed to deserve a separate description. The mechanical parts of our own took about 13 hours to make, including experiments and mistakes; this corresponds to a cost of about \$10.00 for the whole switch, since the cost of materials is practically nil.§

* Potentiometers for Thermoelectric Measurements, Especially in Calorimetry, Walter P. White, J. Am. Chem. Soc., xxxvi, 1874-5, 1914.

† The arrangement of knife switches shown on page 1878 of the same paper has been used, modified for 14 thermoelements, with complete satisfaction for about a year, but it took longer to install, is not so simple in operation, and is harder to overhaul than the one described in the present paper. If the mechanical arrangements of the switch here described had been thought of a little earlier, it would have been used instead. For work with a single potentiometer and a few thermoelements (say, 4 or less) the knife-switch type is probably preferable.

‡ For instance, Hüttner and Tammann describe a calorimetric method wherein, in order to avoid a second thermometer in the furnace, they make, regarding the furnace temperature, an assumption palpably contrary to fact, as Plato has shown (Zs. anorg. Chem. xlv, 721, 1906). And Plato, in his turn, though he did use a second thermometer for his own admirable work, nevertheless, in trying to formulate a method which demands but one, was compelled to make another assumption, also erroneous, regarding furnace temperature (namely, that there is no difference between the temperature of a cooling furnace and that of a charge within it.) In several calorimetric methods, also, precision and convenience have often been sacrificed by the lack of suitable provision for determining the temperature difference between jacket and calorimeter.

§ Of course this estimate might not apply in the case of a factory-made switch.

The electrical arrangements figured here are those appropriate to a four-dial combination potentiometer, with eight connections for various "unknowns," but can easily be modified for other methods of potential measurement. The type of contact used is not suitable for resistance measurements of the highest precision, unless by methods which eliminate the resistance of the contacts. Several features of the arrangement could well be used for resistance measurements, but we have had no occasion to develop any apparatus for such.

The leading features of the switch are the following:

1. The contacts are made between strips of thin sheet copper. This arrangement probably gives as small parasitic electromotive forces as any known, and is evidently among the first also in ease of construction.

2. Sheet celluloid* is used exclusively for insulation, laid over wood where solidity is necessary. This also makes for very low cost of construction, by saving the time needed to work hard rubber. The copper strips are held in place by tacking celluloid strips over them (keeping the tacks away from the copper) or bending the copper over the edges of the celluloid, using shallow notches in the edges of the celluloid, or slits or holes through it, to keep the copper located. Further details on this point seem unnecessary.

3. The contacts are made by pressure alone.† Hence when the pressure is released the moving parts will return to their resting positions if light springs are provided for the purpose. It is sufficient, therefore, in devising any scheme of connections, to arrange for exerting pressure at several points, and this enables an exceedingly convenient system of connections to be very easily obtained.

4. The convenient system of connections in the present case is obtained as follows: A straight wooden rod, when pressed in, presses against the "unknown" (say the thermoelement) contact, closing that. At the same time, a pin, projecting sidewise from the rod, pushes a frame which carries the auxiliary (usually the potentiometer) contacts. A turn of the rod makes the pin strike a different frame, giving a different

* Celluloid does not enjoy the best reputation as an insulator, but I found in two samples of sheet celluloid 0.3^{mm} thick, one over 5 years old, in damp weather, a resistance certainly exceeding 600 megohms between tightly pressed metal conductors of 7^{sq} cm area. Only in air of extreme saturation have I observed detectible surface leakage with it. Of course thin hard rubber can be used like the celluloid, and even with hard rubber bars the switch can not be considered elaborate in view of what it can do.

† The question has often been raised whether pressure, with practically no friction, would give a reliable contact. In five years' experience I have uniformly found that it does, with the surfaces cleaned certainly not oftener than once in three months. The pressure was several hundred grams on each contact surface of about 6 × 20^{mm}, but less would probably have answered.

auxiliary. The rod, when pushed in, is locked by an iron bar. It first raises the bar, unlocking any other rod that may have been in. Hence, finally, to get a connection for any thermolement (or other "unknown") along with its auxiliary, we have only to push the rod for that thermolement, paying no attention to the auxiliary or to any previously connected thermolement; and the auxiliary can be instantly changed for any thermolement by rotating the rod between the thumb and finger.

Detailed Description.

The base is a shallow wooden box, 5^{cm} high inside, and with other dimensions as shown in fig. 2. Pins (cut from wire brads

FIG. 1.

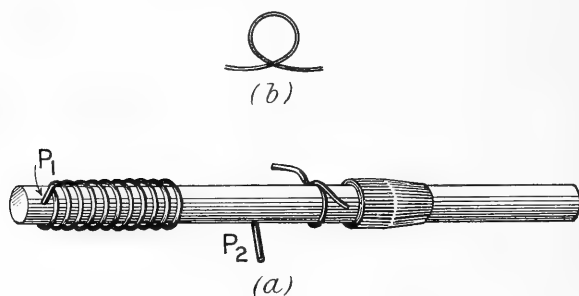


FIG. 1. Operating rod and its orienting collar. 0·4 full size.

about 3^{mm} in diameter) project from it at suitable places to serve for attaching the other parts of the switch. Grooves 1·7^{cm} deep in front and back hold and guide the rod of the lower auxiliary-connecting frame. The floor and sides project 13^{cm} beyond the back.

The *operating rods* (fig. 1) are pieces of 1/2 inch (12^{mm}) birch dowel 18^{cm} long. The brass sleeve is turned from tubing 1·8^{mm} thick, fitting the rod rather closely. It is pinned in place. The coiled spring is for returning the bar when it is unlocked; the pin, P_1 , is to hold the spring. The pin, P_2 , is to move one of the two auxiliary connecting frames. The wire collar (shown separate in fig. 1b) is to prevent the rod from rotating except when purposely turned by the operator. The rod then turns within the rather tight-fitting collar. The collar can never turn far, since the projecting ends would then strike the flat surface of the lower auxiliary frame. Hence the rod, when turned so as to make its pin engage either auxiliary frame, stays so till pressure enough is applied to turn it within the collar.

The *frame for the operating rods* (F, fig. 2) is a rectangular frame made of 4 wooden strips about 20^{mm} square, with holes

giving a very easy fit for the operating rods. It is held in place by slipping over two vertical pins in the base, and can be lifted off at any time. It carries the locking bar, which is a piece of strap iron 2^{mm} thick and 12^{mm} wide, bent as shown and pivoted by two steel pins, P_3 , clamped to the top of the frame. In fig. 2*a*, this bar is shown holding the second operating rod forward, by means of its brass sleeve, while the rod in its turn holds forward the lower auxiliary-connecting frame X_2 . The back of the operating rod frame is fastened to the sides with screws, since it must be removed in order to take out any of the rods.

The *thermoelement leads* are copper strips 0.1^{mm} thick and 6^{mm} in width, which enter through a wide crack left below the back of the base, are fastened (with celluloid insulation, of course) to the wooden strip, E (figs. 2*b* and 3) and then rise vertically, supported by a celluloid strip 8^{cm} high, over whose top their extreme ends are bent as a fastening. The celluloid is cut down from the top to the bar, so as to form a series of tongues, 24^{mm} broad, each carrying a pair of leads. These leads are separated 6^{mm}, or 12^{mm} between centers. They run up on the back, or farther side, of the celluloid.*

To make contact, when the switch is in use, a celluloid tongue is bent back by one of the operating rods, and so presses the copper leads against the *thermoelement bus bars*. This is a wooden support 20^{mm} square, carrying on top a copper strip with teeth 6^{mm} wide, and 24^{mm} apart between centers, projecting down over the first (or near) face, and another strip below with alternating teeth projecting upward. The teeth of course stand opposite the thermoelement leads. From these two toothed strips the electrical connections run to the eliminating switch (not a part of this switch) and thence to galvanometer, potentiometer, etc., in part through the auxiliary bus bars soon to be described. The two pieces of copper are insulated and held in place by sheet celluloid, as already explained. The operating rods do not directly touch the vertical celluloid tongues but press against the obtuse apexes of the broad flat wooden wedges, W , shown in figs. 2, 3. These wedges are 1^{cm} thick, 2^{cm} wide and about 3.5^{cm}

* One form of leakage shielding, hitherto not described, but sometimes desirable, is relatively easy with this arrangement of terminals. (For general principles and methods of leakage shielding, see: *Leakage Prevention by Shielding, Especially in Potentiometer Systems*, Walter P. White, J. Am. Chem. Soc., xxxvi, 2011, 1914). If one thermoelement is in a furnace, or anywhere where shielding is incomplete, and is to remain there while readings of maximum precision are made on another thermoelement, a troublesome leakage current may enter the measuring system by leaking from the disconnected end of the furnace thermoelement at the switch, since insulation alone cannot, as a rule, be relied upon to protect a sensitive thermoelectric system from leakage from power circuits. The remedy is to arrange so that all the pairs of thermoelement leads, when disconnected, are separated from each other within the switch by a shield. To this end, each pair has a separate celluloid strip, and these strips are separated from the wooden parts by two metal plates which are connected to the external shield, are carefully insulated from the rest of the switch, and may even be further isolated, beyond the insulation, by a branch of the internal shield.

FIG. 2a.

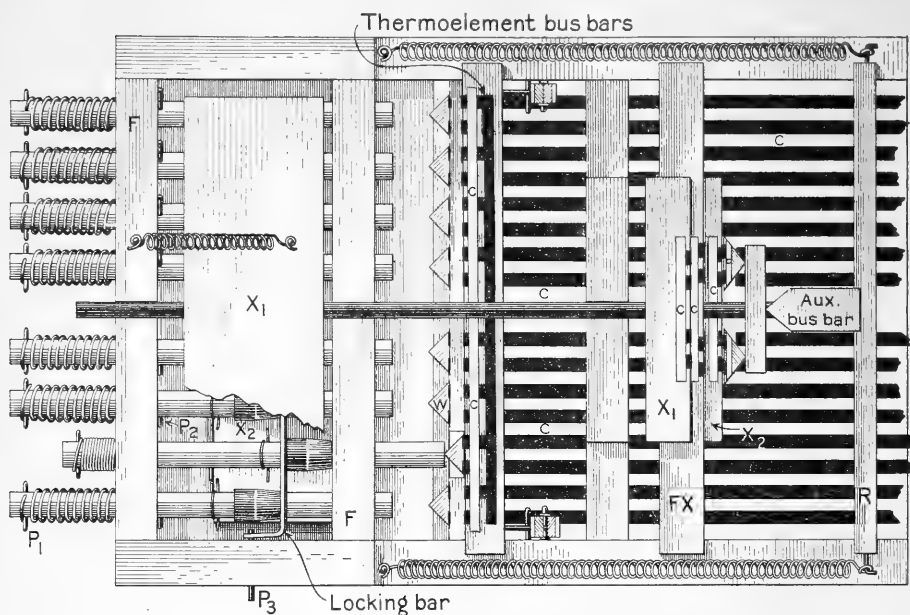


FIG. 2b.

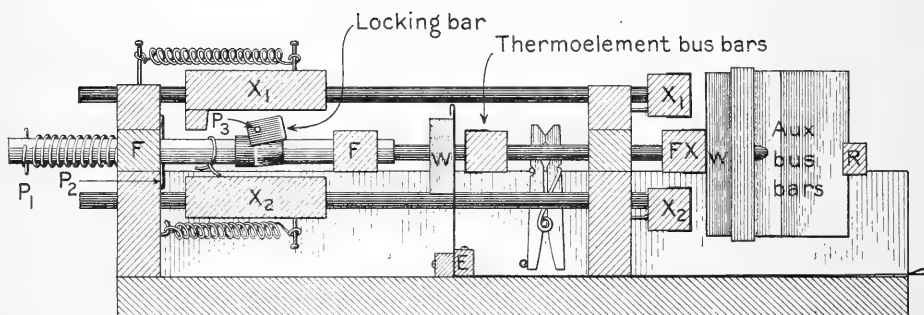


FIG. 2, *a* and *b*. Top view and section of the whole switch. In the view, above, the second pair of thermoelement lead terminals and the lower auxiliary-connecting frame, X_2 , are pushed back (to the right) by an operating rod, and thus put in circuit. In the section below, the fixed auxiliary-connecting frame, FX , is making contact, but the circuit is open at the thermoelement terminals. Scale, $\frac{1}{10}$ full size.

Copper strips are shown full black; other metal and wood, shaded; celluloid insulation, C, clear white. The lettering is otherwise explained in the text.

high. They are fastened to the celluloid tongues by small-headed pins above and below the level of the bus bar. Their function is to insure that the pressure of the operating pin shall be shared by both copper strips. These bus bars are so located that when any operating pin is pushed in and locked, the bars are pushed back 2^{mm} , straining one or both of two stiff springs. Suitable springs are obtained by mounting two spring clothespins at the places shown in figs. 2*a* and *b*, and in the manner shown in fig. 3, so that they are opened when the bus bars are pushed back. The

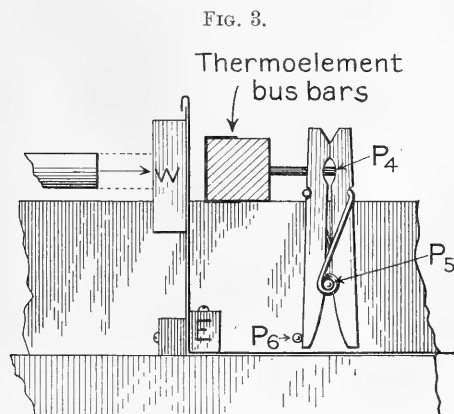


FIG. 3. Detail of thermoelement connecting system from fig. 2, *b*. The pin P_4 is tight in the bus bar support, and passes very loosely through one side of the clothespin, to press against the other side. It prevents the clothespin from sliding off the horizontal steel pins P_5 and P_6 . By pushing the bus bars to the left the clothespin can be removed. Scale, $\frac{1}{4}$ full size.

strip of wood *E*, carrying the thermoelement leads, is so located that the leads, when released, are 6^{mm} from the bus bars.

The two *movable auxiliary-connecting frames*, X_1 and X_2 , fig. 2, are intended to make connection with the appropriate auxiliary apparatus (usually, potentiometer dials) when any one of the thermoelements (or other "unknowns") is connected. Each is made with a $\frac{5}{16}$ inch (8^{mm}) mild steel rod 28^{cm} long, driven with a very tight fit through two strips of wood, one 20^{cm} square and 12^{cm} long, the other 6.5^{cm} wide, 20^{cm} long and 18^{mm} thick. The square strip carries 4 copper strips (fastened and insulated by celluloid, as usual) which are connected to a set of 4 potentiometer switches. The broader strip of wood is pressed by the pins P_2 of the operating rods. The steel rod does not pass through the wood midway of its thickness. In the lower frame, the top of the broad strip must be 12^{mm} below the center line of the operating pins, while the top of the 20^{mm} strip must be 17^{mm} below. Hence the steel rod is 5^{mm} lower in the broad bar than in the narrow one. In the upper frame, the broad strip must be

20^{mm} above the center line, in order to clear the locking bar; hence the iron rod is 3^{mm} nearer the bottom in this strip than in the 20^{mm} strip.

Between the back ends of the upper and lower auxiliary connecting frames is the *fixed auxiliary-connecting frame* FX (fig. 2) which is merely a single square wooden strip provided with 4 insulated copper strips like the others. Like the rod frame it is held in place by two steel pins in the base, and can be lifted off at any time.

Contact with the auxiliary-connecting frames is made by the *auxiliary bus bars* (fig. 2). This arrangement consists of two broad wedges, 8^{cm} long, borne on a wooden cross-piece, which rocks on the wedge-shaped front of another flat piece of wood. The two wedges carry (with suitable insulation) 4 strips of copper, opposite to those on the frames, and running to the battery and galvanometer terminals to which the potentiometer switches are to be connected. The whole is pressed forward by the rod, R, which is pulled by two long springs. The object of the two wedges and rocking cross-piece is, of course, to divide the pressure equally among the 4 contacts. The combination is fastened together as follows: Through the cross-piece, opposite the apex of each of the 3 wedges, are bored 2 holes, large enough to be an easy fit for a small nail. Each hole is then counterbored nearly through so as to take the head of the nail easily. The nails are then driven through into the wedges, far enough to hold these in place but still permit the slight rocking motion required. Pressure against the wedges of course causes no wear or other injury to the holes.

When the movable auxiliary-connecting frames are out of action, the contact strips on them are about 4^{mm} to the front (left, in the figure) from those on the *fixed* auxiliary-connecting frame, so that this frame receives the pressure of the bus bars, and is thereby connected in. When either of the movable frames is pushed in, it pushes the bus bar away from the stationary frame, breaking that connection at the same time as it establishes its own. Thus with 2 movable frames three sets of connections are possible. When the moving frame reaches the bus bars two sets of connections are joined parallel for an instant, but this does no harm in the case of a potentiometer. If in any case this momentary paralleling of connections should be deemed undesirable, it could be avoided by a different, probably slightly less convenient, arrangement of the contacts. The bus bars must be moved about 3^{mm} to clear the stationary frame freely, and after that 8^{mm} further while the thermoelement contact is being established. The springs must be long enough so that this motion of 11^{mm} will not greatly increase the pressure exerted.

The operating rods move 10^{mm} before engaging the movable auxiliary-connecting frames. Hence these frames, at rest, are 10^{mm} from the resting position of the impelling pins, P₁, of the operating rods. This 10^{mm} of motion is used to raise the locking

bar, *b*, and break the previous connection before the coming connection begins to be made. The rods then carry the frame 15^{mm} further. Of this, 4^{mm} brings the frame to the auxiliary bus bars, and then comes the 11^{mm} just described. The travel of the operating rod thus performs three operations, each of which must be finished before the next begins: (1) releasing the previous connection, thus opening the circuit; (2) making the proper contact with the auxiliary bus bars, thus putting into action the proper set of potentiometer switches (or other auxiliaries); (3) closing the circuit as it puts in the desired thermoelement, or other unknown.

The auxiliary bus bars make contact sometimes near their top, and sometimes below, yet they must remain vertical. To secure this a 5/16 (8^{mm}) steel rod is driven tight into the back piece, and runs forward, through a very long bearing. This bearing is formed by a hole in the stationary auxiliary-connecting bar, and one in the front bar of the operating rod frame. The steel rod passes without touching through larger holes in the bus bar cross-piece, in the thermoelement bus bar support, and in the back of the operating rod frame. It must of course be withdrawn (taking away the bus bars) before lifting off any of the structures through which it passes.

To make room for this rod, and for the rods of the movable auxiliary-connecting frames, which are in line with it, above and below, an interval of 40^{mm} is left between centers of the two innermost copper connections of all the sets.

The rod of the upper auxiliary-connecting frame slides in grooves in other blocks, one of which, 20^{mm} high, is permanently nailed upon the front of the operating rod frame; while the other, 40^{mm} high, is fastened by two steel pins to the back of the base so as to be removable. This block also has a hole for the rod of the auxiliary bus bars.

The indispensable eliminating switch* is not included in the present description. At present we are using a triple knife switch as already described,† but we have also used with success something similar to a pair of operating rods, arranged so that each makes the necessary three contacts, instead of two.

For making the necessary electrical connections the various copper strips are left long enough to be clamped together, thus making a system without a single soldered joint, but wires can also be introduced without detriment.

Less cleaning will be needed if the contact surfaces are silver plated. The parasitic thermoelectric forces developed at the contacts are then about three times those for clean bare copper, but are still ordinarily quite negligible in working to tenths of microvolts. The amount of cleaning needed by unplated copper, however, is less than is given to most dial switches. But if corrosive

* Thermoelement Installations, Especially for Calorimetry. Walter P. White, J. Am. Chem. Soc., xxxvi, 1859, 1914.

† Thermoelement Installations, etc., loc. cit., p. 1859.

gases (except chlorine) are likely to be abundant, gold plating might be very desirable.

In order to provide for 16 connections it would be best to have two operating rod frames, one on top of the other, two thermoelement bus bars, and one more auxiliary-connecting frame.

The auxiliary-connecting frames together constitute the "master switch" for the potentiometer used. If this is a combination potentiometer* another arrangement has considerable advantages, though details have not yet been worked out. For it everything resembling a master switch is omitted, and the 4 potentiometer dials are replaced by 40 strips of copper, arranged in parallel lines running from the operator, clamped by a series of wooden strips, insulated with celluloid as in the switch. Above and at right angles to these are several, perhaps 4, sets of contact makers, each consisting of 4 contact pieces sliding on a stout bar, or pair of bars, and performing the functions of the arms of 4 dial switches. Each auxiliary-connecting frame, when pushed back, depresses one of the contact-making bars by means of a suitable connecting mechanism, thus putting into action the particular dial setting made upon that particular bar. This arrangement gives a quadruple potentiometer more easily and cheaply than by a series of dials, and is also more nearly neutral; though it is not quite so completely neutral as a Diesselhorst-Wolff potentiometer.†

Summary.

A switch combination is described, intended to promote rapidity (and, therefore, often accuracy also) in making comprehensive and varied measurements with potentiometers. The type is characterized by the use of contacts between thin copper strips, which is, thermoelectrically, perhaps the best contact obtainable. A new mechanical arrangement greatly promotes convenience and flexibility in operation. Other schemes make construction and overhauling extraordinarily easy.

Geophysical Laboratory,
Carnegie Institution of Washington, Jan. 25, 1916.

* Potentiometers for Thermoelectric Measurements, etc., loc. cit., page 1874.

† Diesselhorst, *Instrumentenkunde*, xxxiii, 1, 1908; Potentiometers for Thermoelectric Measurements, etc., loc. cit., pp. 1871-73.

ART. XX.—*The Edgewood Limestone of Pike County, Missouri*; by R. R. ROWLEY.

THE Edgewood formation of T. E. Savage* begins with the basal Noix oolite, followed by the Cyrene and Bowling Green limestones, but the Cyrene is not at the base of the succession, as stated by Mr. Savage.†

Both C. R. Keyes‡ and Savage err in attempting to correlate in whole or in part the Noix oolite and the Cyrene member. They are very distinct not only lithologically, but faunally and stratigraphically. It is probable that Mr. Keyes has always considered the oolite and Cyrene members as equivalent to each other, and naturally so, since each in certain localities in Pike County directly overlies the Ordovician or the Buffalo shale. The author of this article so considered them for years, but he has lately been fortunate enough to find a locality (the McIlroy farm) where the three members of the Edgewood are present, with the lower two horizons abundantly fossiliferous and each with its characteristic fauna. The south branch of Noix creek at the big C. & A. R. R. bridge near Bowling Green, repeatedly swollen by the heavy rains of the spring and summer of 1915, has cut against the hillside at Mr. Keyes's type locality of the Bowling Green limestone and laid bare the Silurian beds, which here rest upon the Buffalo shales, presenting for study a splendid succession of the Edgewood formation. The oolite, however, is wanting, but the Cyrene member is present, fully developed and equipped with its fossil markers, though with no line of separation to distinguish it from the Bowling Green limestone above. There is neither a lithological line of separation nor an apparent break in sedimentation nor a change in fossil content, for the writer has collected *Atrypa præmarginalis*, *A. putilla* and *Favosites subelongus* from the contact with the Ordovician shale below to the black Devonian? shale above (Grassy Creek).

More or less brown limestone, either of the Cyrene or Bowling Green members, always overlies the basal oolite, but there is usually a dearth of fossils in it; however, the faunæ of the Cyrene beds and the oolite member are closely related, despite the fact that few species pass from the one into the other.

If it were possible, as Keyes suggests, that the oolitic character of the basal beds in the eastern part of the county is merely a local phase, then when the Cyrene limestone replaces

* T. E. Savage, this Journal, xxviii, 1909, p. 517, December.

† T. E. Savage, Stratig. and Palaeont. Alexandrian Series in Ill. and Mo., pp. 19, 25.

‡ C. R. Keyes, Proc. Iowa Acad. Sci., vol. iv, p. 27.

the oolite farther west, it should have, at the least, some of the oolite fauna, which is here not the case. It is true that spots, so to speak, of oolitic character do occur at the Watson locality, and the writer has slabs of this oolitic brown stone filled with the fossil species peculiar to the Cyrene and McCune beds, but without a single form characteristic of the Noix oolite. Usually there is a break in sedimentation between the oolite and the Cyrene beds and a greater difference between their faunæ than between the Cyrene and Bowling Green members; still, the relationship in genera and allied species of fossils is so close that the three horizons may be regarded as faunally continuous.

The McIlroy locality, about nine miles southeast of Louisiana and four miles northwest of Clarksville, presents the three horizons in the same outcrop. Eight feet of pale blue oolite with its usual coral fauna overlies the blue Ordovician shale (Buffalo), and in turn is overlain by eight feet of hard brown limestone carrying the Cyrene fauna and in addition the corals of the Edgewood locality. Nine or ten feet of a soft, almost clayey limestone with few fossils inclosed in rounded nodules overlies the Cyrene bed and is a local phase of the Bowling Green member.

It is peculiar that the eight feet of oolite at McIlroy, with its fauna, should disappear before the Cyrene locality, five miles southwest of McIlroy, is attained, yet such is the case.

The oolite has its greatest thickness along the Mississippi river front and thins out rapidly westward, disappearing altogether five or six miles west of Louisiana. It therefore follows that where the oolite is thickest, the brown stone is thinnest, and vice versa.

At Louisiana along the Mississippi river the oolite in two heavy beds attains a thickness of eight feet, while the brown stone is scarcely eighteen inches thick. However, at the mouth of Buffalo creek two miles southeast of Louisiana, in the bluff facing the river, the brown stone is over eight feet thick, while the oolite is a little less. Near the C. & A. R. R. bridge, two and a half miles northeast of Bowling Green, the total thickness of the Silurian beds is quite thirty feet, including the type outcrop of the Bowling Green limestone, and the recently uncovered Cyrene beds below, the former alone having a depth of over twenty feet.

Half a mile southwest of Vera or Watson station, in the first cut along the C. & A. R. R., the Cyrene beds are replaced by the Watson horizon which rests on the Ordovician shale and yields an abundance of fossils, but of few species, notably *Atrypa premarginalis*. The Watson bed is either the very base of the Bowling Green limestone, with which it agrees

lithologically, or should be regarded as another member of the Edgewood formation.

Three miles north of the town of Edgewood and about three miles east of Cyrene is Savage's type locality of the Edgewood formation, the basal beds, here richly fossiliferous, consisting of thin layers of a fine-grained clay limestone that directly overlies the Maquoketa or Buffalo shale.

Dalmanella edgewoodensis, *Schuchertella missouriensis*, *Dalmanites danai*, and *Atrypa putilla* are the characteristic fossils of the Cyrene limestone. The type locality for this member is generally known as the Wigginton place, and is at the foot of a hill locally known as Buffalo Knob. The five or six feet of Cyrene beds here are overlain by a coarser and heavier brown limestone, locally bluish and massive, of considerable thickness that outcrops along the hillside. This is the Watson limestone, above which are eight to ten feet of a very sandy yellowish blue shale, the equivalent of the Bowling Green limestone. Less than a mile north of the town of Edgewood is an outcrop representing all the members of the Edgewood formation except the oolite, the Cyrene member overlying directly the Ordovician (Buffalo) shale. Above the two or three feet of Cyrene limestone is the coral horizon, which is thirty-six to thirty-eight inches thick, and which is the equivalent of perhaps the whole of the Watson limestone, though the lower part also embraces the *Atrypa putilla* zone of the Cyrene member. For a mile or two down the branch that has exposed the rocks at this locality, favositoid, thesoid and lyelliod corals occur in great numbers, with occasional specimens of *Atrypa præmarginalis* and a rhynchonelloid. The two layers of this Edgewood locality, five or six feet thick, are of the Bowling Green member.

The Silurian beds at McCune station on the "Short Line" or Hannibal and St. Louis R. R., represent the Cyrene, Watson and Bowling Green horizons. The characteristic fossils are *Atrypa putilla* and *A. præmarginalis*.

At one locality along the road from the Wigginton place to the town of Edgewood the following section was observed: at the top are nine or ten feet of what appears to be a yellow-blue sandy shale, or rather a fine-grained yellowish laminated sandstone, with many casts of small fossils, then seven or eight feet of a massive pale blue limestone with few recognizable fossils, at the base three or four feet of flaggy Cyrene limestone resting on two or three inches of a bluish oolite. Immediately below the oolite is a flaggy Ordovician shale (Buffalo) with a scant fauna of Richmond fossils. Half a mile further west the oolite is entirely wanting.

At some localities the oolite is in two layers and white, while at others it is brown, and again in but one layer of a pale blue color.

Corals of the cyathophylloid, favositoid and lyellioid forms are often abundant in the oolite, especially along the line of separation between the two layers, but the most trustworthy guide fossils are *Atrypa tubulistriata* and *Cyclonema daytonense*. At the Edgewood locality the corals occur sticking in the rock like plums in a pudding, and the slopes of the low hills on either side of the brook yield beautifully preserved specimens.

Of the species of fossils that extend through the entire thickness of the Edgewood beds may be mentioned *Leptæna rhomboidalis*, *Orthis flabellites*, *Favosites subelongus*, *Halysites catenulatus*, *Clathrodictyon vesiculosum*; and of the genera rich in species: *Schuchertella*, *Dalmanella*, *Homœospira*, *Bellerophon*, *Favosites*, *Lyellia* and *Streptelasma*.

As represented in the northern and eastern parts of Pike County, Missouri, the Edgewood formation lies between the Devonian? shales (Grassy Creek) above and the Buffalo shales (Maquoketa or Richmond) below, while in the southern district it is overlain by a few feet of brown fossiliferous Onondaga limestone that separates it from the grassy shale.

Louisiana, Mo.

ART. XXI.—*Description of Large Cylinders of Scoriaceous Diabase in the Normal Holyoke Diabase*; by B. K. EMERSON.

THERE has been in the Amherst College Museum for many years a great block of diabase labelled "Tuff with tree trunks, from Amherst." It is described by Prof. C. H. Hitchcock in "Guide to Amherst College Collections 1862."

It is a great bowlder and came doubtless from the trap sheet in Deerfield Mountain several miles north of Amherst. It is 2 ft. by 1 ft. by 9 inches, and has been much broken in developing the tubes. A smaller piece, apparently broken from the main mass, is 22 inches by 6 inches by 9 inches. The rock must have been called tuff without careful inspection; because the tubes simulate small straight tree trunks so perfectly, the inference was made that the enclosing rock must be tufaceous. A thin section showed it to be the normal diabase of the Deerfield bed, and a section of the tubes showed a greatly decomposed diabase with a fibrous monoclinic zeolite, apparently scolecite, filling the cavities.

There are two of these cylinders on one side of the big block and one on the other; and one on the smaller block (see fig. 1). They are straight and closely parallel with each other, and taper exactly like a tree trunk. One nearly circular cylinder is $2\frac{1}{8}$ inches at one end and $1\frac{1}{2}$ inches at the other. Others are slightly flattened, fluted or in places triangular with rounded sides. One is 3 inches by $1\frac{1}{2}$ at one end and 2 inches by $1\frac{1}{2}$ at the other. The longest tube is 22 inches in length and broken off at both ends. They are scoriaceous the whole length but mostly so on the outside. The cavities are small, averaging about $\frac{3}{16}$ of an inch.

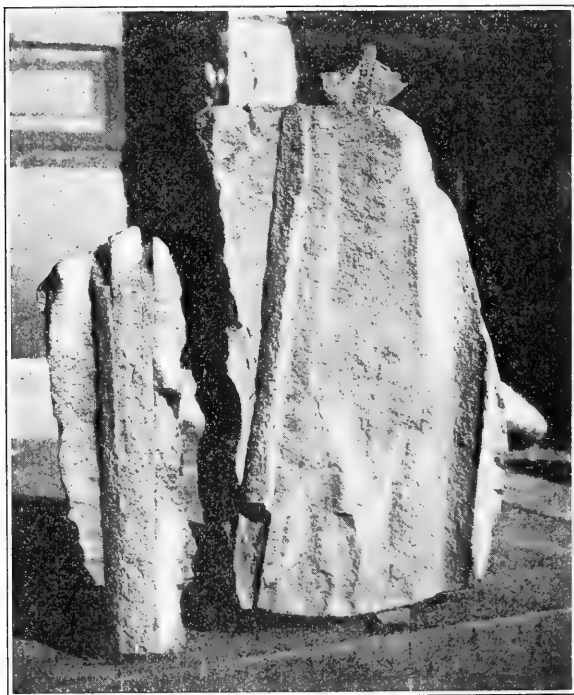
Recently a smaller piece three inches long was found as a bowlder about a mile southeast of the Mount Holyoke House, where it could easily have been brought from the Deerfield sheet. It is 3 inches long, $1\frac{1}{2}$ by $\frac{3}{4}$ at one end and $\frac{1}{2}$ inch in diameter at the other, and with coarser and thicker steam holes. The containing rock is a quite coarse diabase, with many porphyritic feldspar crystals, much like the coarser portion of the Deerfield sheet.

The Deerfield sheet is composite, at least two bands of scoriaceous rock occurring in the central portion of the mass. The enclosing rock in the two blocks is a diopside diabase of the same type as the rock at the upper surface of the sheet at the Lookout above the city quarry in Greenfield, where the large quantities of the subjacent wet sand were carried explosively up into the central portion of the sheet from below.*

* Bull. Geol. Soc. Amer., vol. viii, p. 59, 1897.

As a line of bubbles escapes upward from a porous body submerged in water, columns of such bubbles may have risen from such an enclosure as the above, boring holes in the viscid mass and these might be filled by the porous trap. I have seen empty parallel holes on the surface of the trap $1\frac{1}{2}$ inch wide and $\frac{1}{4}$ inches deep at Titan's Piazza in the Holyoke Range.

FIG. 1.



I have also seen at Kilauea a hollow tube in the lava 4-5 inches in diameter and perhaps a foot deep where the liquid lava had surrounded a small tree and became solid so quickly that the trunk on burning or rotting left a cylindrical cavity. A second scoriaceous flow might have filled this hole and made a result like that here described. That is, however, a rather far-fetched explanation, especially as the trap in the block adjacent to the tubes is of the same texture as farther away from these tubes.

Amherst, Mass.

ART. XXII.—*The Charnockite Series of Igneous Rocks*; by
HENRY S. WASHINGTON.

Introduction.

ABOUT fifteen years ago T. H. Holland* described a series of igneous rocks which are found at various localities in Madras and elsewhere in southern India. They are said to form a well-defined comagmatic region or petrographic province of Archæan age,† the members of which range from a highly silicic hypersthene granite, through intermediate types, to norites and pyroxenites. Holland gave the name charnockite to the granite, and proposed the designation “Charnockite Series” for the whole group, in order to distinguish the rocks of this petrographic province for survey purposes. He urged the importance of applying the terms only to the rocks of India. The term “series” was thus used by him much as it had been used by J. D. Dana‡ twenty years before for the igneous rocks of the “Cortlandt Series.” While Dana did not explicitly recognize the concept of a petrographical province, enunciated later by Judd, yet he seems to have had some idea of the “consanguinity” of the rocks.

Holland's descriptions are quite detailed, but the analyses which he cites are not very satisfactory, chiefly because of the non-separation of the iron oxides, and to a less extent because none of the minor constituents was determined. The high summations are most probably due to the FeO being reckoned as Fe₂O₃, the extra oxygen involved increasing the apparent sum.

As the rocks are of importance in Indian geology and are of considerable petrological interest in that they present great similarities with rock series elsewhere, a chemical reëxamination was deemed advisable. At the request of Dr. L. L. Fermor, the Geological Survey of India, through Mr. Guy C. Pilgrim, sent me five excellent specimens of typical representatives of the charnockite series, the specimen numbers being the same as some of those described by Holland. There were also sent some representative specimens of the Deccan traps, which will be analyzed and described later.

I take pleasure in expressing my sincere thanks to these gentlemen for their courtesy, as well as to Mr. H. H. Hayden, Director of the India Survey, for permission to publish the results of my studies. I have also to thank Drs. H. E. Merwin and N. L. Bowen, of this laboratory, for their kindness in

* T. H. Holland, Mem. Ind. Geol. Surv., xxxviii, pp. 121-249, 1900; he cites previous literature.

† Idem, C. R., xii, Congr. Geol. Int., p. 378, 1914.

‡ J. D. Dana, this Journal (3), xx, p. 194, 1880.

examining optically the hypersthene and feldspar respectively. For discussion of the localities, geological occurrence, origin, and other details, Holland's paper may be consulted.

Charnockite (Hypersthene granite).

This specimen (9.658)* is from the central part of Magazine Hill, St. Thomas' Mount, eight miles south of Madras, the type locality.

It is very fine-grained, looking much like a dense quartzite, of a dark, somewhat greenish, brownish gray, and a vitreous, almost greasy, luster. None of the constituent minerals can be definitely distinguished with the lens. Holland gives the specific gravity as 2.67.

The microscope shows it to be composed in great part of quartz and alkali feldspar, with a little oligoclase, and hypersthene, and less biotite and magnetite. The texture is granitic, the individuals being all anhedral and with consertal fabric.

The quartz is clear and I could detect none of the hair-like inclusions mentioned by Holland (p. 138), nor is the quartz blue in my specimen. The alkali feldspar usually shows the common microcline striations, though much is free from them. The oligoclase shows very fine multiple lamellæ, with extinctions corresponding to Ab_6An_1 . The pyroxene forms small, very irregular grains, colorless but with a trace of pleochroism, which is so faint as to be discernible only after study of the other rocks.† The scheme is c colorless, a and b faint pink. The cleavage lines are very coarse and the extinction often oblique to them, a peculiarity which will be discussed later. There are a few flakes of brownish biotite (not mentioned by Holland), and fewer grains of magnetite.

The mode, determined by Rosiwal's method, is as follows:

Quartz	40
Microcline	48
Oligoclase	6
Hypersthene	3
Biotite	1
Magnetite	2

It is clear, on comparison with the norm, that some of the anorthite molecule must be present in the unstriated feldspar, which is reckoned as microcline. This feature will be met with in other members of the series.

* These are the India Survey numbers on the specimens.

† Judging from Holland's descriptions of the pleochroism and other optical properties of the minerals, in all the specimens, it is probable that the thin sections studied by him were considerably thicker than mine.

An analysis gave the results shown in A of Table I, there being given also the two analyses published by Holland.

TABLE I.
Analyses of Hypersthene Granites.

	A	B	C	D	E	F
SiO ₂	77.47	75.54	75.30	73.47	71.85	71.80
Al ₂ O ₃	11.00	13.75	11.40	15.42	15.25	14.90
Fe ₂ O ₃	1.04	4.99	5.40	0.26	1.04	1.10
FeO	2.02	n. d.	n. d.	0.67	2.56	1.08
MgO	0.43	0.69	0.60	0.20	0.63	0.39
CaO	1.02	0.94	0.75	1.35	2.46	2.20
Na ₂ O	2.86	1.55	1.45	5.57	3.18	4.17
K ₂ O	4.14	3.34	6.13	3.64	3.04	4.11
H ₂ O +	0.20	0.28	----	n. d.	0.17	0.60
H ₂ O -	0.05	----	----	----	----	----
TiO ₂	0.26	----	trace	0.12	0.58	0.26
P ₂ O ₅	none	----	----	----	trace	----
MnO	none	----	----	----	trace	----
	100.59	101.08	101.03	100.79	100.76	100.61

A. Charnockite (1.3". 2.3). St. Thomas' Mount, Madras. (9.658). H. S. Washington analyst.

B. Charnockite. Same locality. T. L. Walker analyst. T. H. Holland, Mem. Ind. Geol. Surv., xxxviii, p. 142, 1900.

C. Charnockite. Same locality. P. C. Roy analyst. T. H. Holland, op. cit., p. 142.

D. Hypersthene granite (1.3.2.4). Birkrem, Soggendal, Norway. C. F. Kolderup, Berg. Mus. Aarb., 1896, No. v, p. 98.

E. Hypersthene adamellite (1.3.2.3). Jones Sound, Ellesmere-land. P. Schei analyst. C. Bugge, Rep. 2nd Fram Exp., No. 22, p. 18, 1910.

F. Hypersthene granite (1.4.2.3). Mount Gbon, Ivory Coast. Pisani analyst. A. Lacroix, C. R., cl, p. 21, 1910.

The material represented by my analysis is distinctly more silicic than that of the other two,* and it is probable that the central mass of charnockite is not entirely uniform, though the variation is apparently not very great. The marked difference in the figures for potash in B and C renders them (one or both), somewhat open to suspicion. The high summations of these two are, presumably, to be attributed to the estimation of FeO as Fe₂O₃. Not a trace of manganese could be detected in A, although this element is almost universally present in igneous rocks. The other analyses will be referred to subsequently.

*Holland mentions dikes cutting the charnockite, which are composed wholly of quartz and feldspar, with no pyroxene.

The norm of A is given below. Those of the other two are not given, because of the non-separation of the iron oxides and the uncertainty as to the alkalis. The norms of both show an excess of Al_2O_3 , in B amounting to 5.92 per cent, which is incompatible with their modes.

Q	41.22
Or	24.46
Ab	24.10
An	5.00
Hy	3.34
Mt	1.62
Il	0.61

This places the rock in tehamose, with the symbol I.3".2.3. B would also fall in I.3.2.3, and C in I.3.1.2, but for these analyses these symbols are of little significance.

Hypersthene Quartz diorite. ("Intermediate Charnockite".)

Intermediate between the most and the least silicic members of the series are many rocks which show, according to Holland, a considerable diversity in characters. These do not occur at St. Thomas' Mount or Pallavaram, but are widely distributed over the Madras Presidency and to the west. The only representative of these which I have is a specimen (11.915) from Arthur's Seat, Yercaud, in the Shevaroy Hills, Madras.

In the hand specimen this much resembles the typical charnockite, being dense and of the same brownish gray color. The grain, however, is distinctly coarser, and the large specimen shows quite distinct, though irregular, variations in this character. Small black grains of pyroxene are scattered through a granular mass of quartz and feldspar, though it is almost impossible to distinguish these with the lens. The specific gravity is about 2.77.

Microscopically, also, its characters are much like those of the charnockite. The texture is granitic. The quartz shows no hair-like inclusions and occasionally shows undulatory extinction. The feldspar is, apparently, largely alkalic, some of it showing the microcline grating, while the greater part shows no twinning lamellæ. Some of this latter, as pointed out by Holland, contains small colorless, elongated or fusiform inclusions, with slightly higher birefringence and refraction than the feldspar, arranged in parallel position. They are apparently composed of quartz. Soda-line feldspar is much less abundant than the alkalic, to judge by the small number of individuals with albite twinning lamellæ, the extinctions corresponding to the composition Ab_3An_1 . Some of these also

contain the fusiform inclusions just mentioned. As the norm shows that a much greater amount of the anorthite molecule is present than is accounted for by the actual proportion of obvious andesine present, a very considerable proportion of the unstriated, and hence apparently alkalic feldspar, is probably sodicalcic. This supposition was confirmed by an examination kindly made by Dr. N. L. Bowen, which showed that a great majority of the feldspar grains had a refractive index of about that of Ab_3An_1 .

The pyroxene is entirely a hypersthene, in subhedral and often somewhat rounded grains. These are colorless, but with a distinct pleochroism: *c* slightly bluish gray, *a* and *b* pale pink. The parallel cleavage cracks are rather coarse, and here also many individuals show oblique extinction. There is no hornblende or biotite. Magnetite is more abundant than in the preceding type, as small, highly irregular masses mostly interstitial between the other minerals, and seldom included in them. There are a few very small prismoids of apatite.

The mode, determined by Rosiwal's method, is approximately as follows, no distinction being made between the twinned and untwinned feldspars.

Quartz	15.5
Feldspar	55.5
Hypersthene	23.6
Ores	5.4

On comparison with the norm it would appear that a little quartz has been overlooked—or that it is possibly occult, and that some of the anorthite molecule has gone into modal pyroxene.

The two analyses A and B were made on specimens with the same number, so that practically identical composition between them may be assumed; but there are some discrepancies between the two analyses. The higher " Al_2O_3 " in B may be accounted for by the non-determination of TiO_2 and P_2O_5 , and also probably by the co-precipitation of some MgO .* The higher CaO in B is more difficult to account for. With these exceptions the two analyses agree very well.

The norm of A is as follows:

Q	20.95
Or	6.67
Ab	31.44
An	20.57
Di	1.36
Hy	13.74
Mt	3.25
Il	1.52

* In A, $Al_2O_3 + TiO_2 + P_2O_5 + MgO = 19.07$; in B, $Al_2O_3 + MgO = 18.79$.

TABLE II.

Analyses of Quartz diorites.

	A	B	C	D	E
SiO ₂	63·85	63·77	64·35	63·22	59·50
Al ₂ O ₃	14·87	16·30	15·46	17·46	18·71
Fe ₂ O ₃	2·32	7·49	7·50	1·35	2·32
FeO	5·07	n.d.	n.d.	3·40	3·96
MgO	3·29	2·49	0·50	2·05	3·49
CaO	4·48	6·33	3·58	4·91	5·10
Na ₂ O	3·72	3·68	3·28	5·12	3·82
K ₂ O	1·09	1·21	3·54	1·31	1·18
H ₂ O	0·11	none	---	0·60	0·60
TiO ₂	0·83	---	1·68	0·74	1·68
ZrO ₂	trace	---	---	---	---
P ₂ O ₅	0·08	---	---	0·07	0·07
Cl	none	---	---	---	---
S	0·15	---	FeS ₂	0·44	---
Cr ₂ O ₃	none	---	---	---	---
MnO	0·05	---	---	---	---
BaO	none	---	---	---	---
SrO	0·04	---	---	---	---
	<hr/> 99·95	<hr/> 101·27	<hr/> 99·94	<hr/> 100·67	<hr/> 100·43

A. Quartz-hypersthene diorite (II.4.3.4"). Yercaud, Shevaroy Hills, Madras. (11·915.) H. S. Washington analyst.

B. "Intermediate charnockite." Same locality. (11·915.) T. L. Walker analyst. T. H. Holland, *op. cit.*, p. 151.

C. Banatite. Dypvik, near Farsund, Norway. C. F. Kolderup analyst. *Berg. Mus. Aarb.*, 1896, No. v, p. 123.

D. Hypersthene-quartz diorite. (II.4.3.4.) Foulke Fjord, Ellesmere Land. P. Schei analyst. C. Bugge, *Rep. 2nd Fram Exp.*, No. 22, p. 18, 1900.

E. Hypersthene granite. ("II.4.3.4.") Mount Zan, Ivory Coast. Pisani analyst. A. Lacroix. *C. R.*, cl, p. 21, 1910.

The rock therefore falls in tonalose, with the symbol II.4.3.4". The three analyses of rocks from the similar regions of Norway, Ellesmere Land, and the Ivory Coast resemble the India one in general features, though in each there are certain divergences. They will be discussed later.

Norite. ("Basic Charnockite").

Two specimens of this type are represented. One (9·660) is from St. Thomas' Mount, where it forms the two ends of Magazine Hill. The other (9·673) is from Pammal Hill, at Pallavaram, 11 miles south of Madras. They are both fine-grained, dark gray or almost black, showing an even mixture

of small glistening black pyroxene and hornblende grains with a little interstitial whitish feldspar. The specific gravity of 9.660 is 3.02 according to Holland.

In thin section the two specimens are much alike. The texture is granitic, as in the preceding types. There is much soda-lime feldspar, which is highly twinned according to the albite law, the extinctions indicating a general composition of about Ab, An_1 , as was also observed by Holland. An unstriated feldspar is present in almost equal quantity. This has a refractive index decidedly higher than the Canada balsam, and must also be considered to be labradorite, at least in great part. This conclusion is the more justified as the norm shows that very little orthoclase can be present. Holland (p. 157) comes to the same conclusion, on other grounds.

In my specimens the pyroxene is mostly hypersthene, similar to that already described, though the pleochroism is rather weak. In the St. Thomas' Mount rock (but not in that of Pallavaram) there is also a small amount of a grayish, slightly pleochroic monoclinic pyroxene (augite), which is distinguishable from the orthorhombic by its very marked oblique extinction, higher birefringence and better cleavage development. There is a considerable amount of hornblende, which, in the St. Thomas' Mount rock is less than, and in that of Pallavaram more than, that of the pyroxene. The color is a greenish brown, with the pleochroism noted by Holland: a = pale brownish yellow, b = yellowish brown, c = brownish green. The hypersthene and hornblende would seem to be of about the same age, as each is found included in the other. The hornblende is not secondary. A very few small rounded grains of olivine are seen in both specimens. Small anhedra of magnetite are present, being more abundant in the St. Thomas' Mount rock. There are some small apatites, but I could detect no spinel. All the constituents are absolutely fresh.

The mode of the St. Thomas' Mount rock is as follows, the two pyroxenes being reckoned together:

Feldspar	40.8
Pyroxene	31.0
Hornblende	19.6
Ores	8.6

Analysis B is only partial, but the discrepancies between it and A are similar to those in the case of the quartz diorite, and are probably to be ascribed to the same causes. The divergence in the two figures for SiO_2 and the presumably lower alkalis are difficult to understand, unless it implies considerable variation in the composition of the mass. The other analyses will be discussed later.

The norm of A is as follows :

Or	5.00
Ab	26.20
An	15.29
Di	19.43
Hy	20.27
Ol	5.63
Mt	3.71
Il	3.65
Ap	0.34

This places the rock in camptonose, with the symbol III.5.3.4". It will be seen that, allowing some of the albite molecule for alkali feldspar, and some anorthite to enter hornblende, the normative feldspar is essentially of the composition Ab_1An_1 , confirming the view that by far the greater part of the unstriated feldspar is labradorite.

TABLE III.
Analyses of Norites.

	A	B	C	D	E
SiO ₂	50.04	53.38	52.21	51.49	54.33
Al ₂ O ₃	11.65	19.38	19.24	20.72	11.43
FeO	15.76	15.39	10.46	7.28	7.47
Fe ₂ O ₃	2.63	n.d.	n.d.	1.80	6.10
MgO	5.58	2.79	2.36	3.82	11.70
CaO	7.89	7.68	7.28	6.71	4.25
Na ₂ O	3.08	n.d.	3.48	3.70	3.52
K ₂ O	0.89	n.d.	1.09	2.14	0.59
H ₂ O	0.19	---	---	0.41	0.60
TiO ₂	1.93	---	3.12	2.26	0.13
P ₂ O ₅	0.20	---	1.21	0.15	0.06
	99.64	98.62	100.45	100.72*	100.18

A. Hornblende norite. (III.5.3.4".) St. Thomas' Mount, Madras (9.660). H. S. Washington analyst.

B. Hornblende norite. Same locality (9.660). T. L. Walker analyst. T. H. Holland, op. cit., p. 156.

C. Quartz norite. Rekefjord, Soggendal, Norway. C. F. Kolderup analyst. Berg. Mus. Aarb., 1896, No. v, p. 79.

D. Norite (II.5.3".4). Near Peekskill, N. Y. G. S. Rogers analyst. Ann. N. Y. Ac. Sci., xxi, p. 61, 1911.

E. Norite (III.5.3.(4)5). Zoanle, Ivory Coast. Pisani analyst. A. Lacroix, C. R., cl., p. 21, 1910.

Bahiaite (Hornblende hypersthenite).

A perfectly fresh specimen (9.672) of this type of the "ultra-basic" members of the series, from Pammal Hill, Pallavaram,

* Includes all .11 S and .13 MnO.

11 miles south of Madras, was examined. It is a black, medium-grained rock, composed entirely of glistening grains, from 1–3^{mm} in diameter, of pyroxene and hornblende. The luster from the cleavage faces is especially marked in the two largest parallel faces of the specimens, indicating a schistose structure. The microscope shows that the rock is composed essentially of hypersthene and hornblende, with much less augite, a small amount of magnetite and very little apatite. The texture is granitic, all the constituents being anhedral, with consertal fabric. The specific gravity of a similar specimen is given by Holland as 3.333.

The abundant hypersthene is colorless, with a pleochroism which is similar to that in the preceding types, but much more intense: *c* blue gray, *a* and *b* flesh pink. The crystals usually carry the characteristic schiller inclusions, in the form of excessively thin, straight rods, which commonly form a core in the center. In practically all longitudinal sections the cleavage cracks are rather coarse, and the extinction is frequently oblique. This fact, which has been noted in the case of the hypersthene of the preceding types, at first gave rise to the idea that the supposed orthorhombic pyroxene was in reality monoclinic. Dr. H. E. Merwin, however, very kindly examined the mineral grains and found that the refractive indices are much lower than that of augite, about that of hypersthene, that they are optically negative, and that in cleavage flakes the extinction is always parallel to the cleavage cracks. This pyroxene, therefore, is certainly hypersthene, and the apparently anomalous oblique extinction is to be ascribed to the non-development of the usual prismatic cleavage, the coarse cleavage cracks seen being due to the parting or cleavage parallel to *b*(010).

Augite is much less abundant, and closely resembles that in the St. Thomas' Mount norite, except that the pleochroism is a little more marked. Some of the augites also show schiller inclusions. The abundant hornblende is of a rather bright yellow green color, with a pleochroism almost identical with that in the norite, except that all the tones are decidedly greener. The hornblendes also carry the schiller inclusions, which are coarser than in the hypersthene and sometimes slightly curved. All the hornblende is primary.

Small magnetite anhedrala are fairly common, occurring both between and as inclusions in the other minerals. The usual small apatites are present. No olivine could be detected with certainty, nor could I find any of the green spinel mentioned by Holland. There is absolutely no feldspar of any kind. All the constituents are perfectly fresh and unaltered.

The mode is as follows, about 5 per cent of augite being estimated to be present:

Hypersthene	46.0
Augite	5.0
Hornblende	40.7
Ores	8.3

TABLE IV.

Analyses of Pyroxenites.

	A	B	C	D	E
SiO ₂	47.44	48.86	49.95	51.23	51.83
Al ₂ O ₃	5.36	9.80	6.52	6.17	7.98
Fe ₂ O ₃	3.13	16.35	1.50	1.96	1.48
FeO	12.42	n.d.	10.41	6.95	8.28
MgO	19.96	18.08	17.02	26.52	24.10
CaO	7.60	9.57	11.77	4.03	5.26
Na ₂ O	0.48	trace	0.98	0.29	0.35
K ₂ O	0.10	trace	0.52	0.12	0.06
H ₂ O	0.08	0.67	0.81	0.24	0.29
TiO ₂	1.29	----	0.15	0.27	0.29
ZrO ₂	none	----	----	----	----
P ₂ O ₅	0.27	----	none	none	0.09
S	0.34	----	none	0.41	----
Cr ₂ O ₃	0.07	----	0.10	0.31	0.31
MnO	0.15	----	----	1.46	trace
NiO	----	----	----	----	0.11
BaO	none	----	----	none	----
CuO	----	----	----	0.21	----
	100.69	101.33	100.09	100.17	100.43

A. Bahiaite (hornblende hypersthene) (IV".1".2.1.2). Pam-mal Hill, Pallavaram, Madras, (9.672). H. S. Washington analyst.

B. Pyroxenite. Pallavaram, Madras. (9.394.) T. L. Walker analyst. T. H. Holland, *op. cit.*, p. 166.

C. Pyroxenite, Montrose Point, New York. (IV.1.2.2.2.) G. S. Rogers analyst. *Ann. N. Y. Ac. Sci.*, xxi, p. 62, 1911.

D. Bahiaite (hornblende hypersthene). (CIV").1 (2.1.(1)2). Maracas, Bahia, Brazil. H. S. Washington analyst. *This Journal*, xxxviii, p. 85, 1914.

E. "Pyroxenite." Near Meadow Creek, Montana. (IV.1.-1(2).1.2). L. G. Eakins analyst. G. P. Merrill, *Proc. U. S. Nat. Mus.*, xvii, p. 658, 1895.

The specimens represented by A and B do not bear the same number, but they come from near each other and must be closely alike. Here we see the same discrepancies as in the previous cases. The norm of A is as follows:

Or	0.56
Ab	4.19
An	12.23
Di	18.97
Hy	42.35
Ol	13.01
Mt	4.41
Il	2.43
Ap	0.67

This gives the rock the symbol IV¹.1".2.1.2, that is in the subrang named hilose by Daly. The rock from Bahia falls in the same position, while the other two, C and E, with the symbol IV.1.2.2.2, fall in a subrang which has been called palisadose by J. V. Lewis (1908) and hudsonose by Rogers (1911).

The name bahiaite from an occurrence in Brazil was recently suggested* for the phanerites composed essentially of hypersthene and hornblende, the name being of equal nomenclatorial rank with wehrlite, lherzolite, saxonite or cortlandtite. The rock has been noted by Rogers in the Cortlandt Series, by Merrill in Montana and as India furnishes another locality, whose rock closely resembles the type, the motex (combination of mode and texture), is seen to be very widespread, and the application of the name would seem to be justified.

General Characters.

The general characters—modal and chemical—of the Indian Charnockite series may be summed up as follows:

The rocks range from highly quartzose hypersthene granite (charnockite), through hypersthene-quartz diorites (and possibly monzonites), norites and other intermediate rocks to hornblende hypersthenite.

Except in the granite little or no microcline is present, the dominant feldspar in the intermediate types ranging from Ab₃An₁ to Ab₁An₁. A very striking peculiarity of these soda-lime feldspars is the tendency to absence of the usual twinning lamellæ, so that they simulate orthoclase. The characteristic and constant mafic mineral is hypersthene, which is high in FeO, and with a constant peculiar pleochroism: c bluish gray, a and b pink. This hypersthene is also characterized by the prevalence of the cleavage or parting parallel to *b*(010), and the general absence of the usual prismatic cleavage, so that many sections show apparent oblique extinction. Augite, when present, is only in very subordinate amount and is apt to show a faint pleochroism like that of the hypersthene. Hornblende (like augite) occurs only in the more mafic members, but offers no

* H. S. Washington, this Journal, xxxviii, p. 86, 1914.

specially striking peculiarities. Biotite is almost wholly absent. The ores are either ilmenite or a titaniferous magnetite, and form a constant, though subordinate constituent. Holland mentions garnet and titanite in some cases, but they were not seen in my specimens.

Chemically, the series shows a very great range in silicity, SiO_2 varying from 77.5 to 47.5 per cent. Alumina is rather low, never more than enough to satisfy the combined alkalis and lime, and its amount is fairly constant. The iron oxides are high, with FeO greatly predominating over Fe_2O_3 . Except in the pyroxenite, magnesia is low, and consistently below the iron oxides reckoned as FeO . Lime also is not high, but a notable amount of it is always present, even in the most silicic rocks. However, its amount is generally not more than enough to satisfy the excess of alumina over alkalis to form the anorthite molecule, except in the most femic members, where a small part of it enters the diopside molecule as modal hornblende and augite. The alkalis are rather high and soda dominates largely over potash, except in the charnockite where the amounts are about equal. Titanium, phosphorus, and manganese are consistently low, and the rocks carry but traces of barium, strontium and chromium, and no zirconium.

Comparison with other Regions.

Comagmatic regions comparable with that of southern India are few, though widely scattered. Those which can be surely correlated, as has been suggested by the petrographers who described them, are: the Ekersund, Soggendal and Bergen Districts in western and southwestern Norway;* the eastern part of Ellesmere Land and Prudhoe Land opposite across Smith Sound;† the "Cortlandt Series," near Peekskill, New York;‡ and the Ivory Coast, in West Africa.§ Another similar region in the Blue Ridge of Virginia has been studied by T. L. Watson, whose description appears in the Bulletin of the Geological Society of America, 1915.

It has been suggested that the anorthosite area of Volhynia || is also analogous to the Indian district. There is also much in common with the anorthosite areas of eastern Canada¶ and the

* C. F. Kolderup, *Berg. Mus. Aarb.*, 1896, No. v; ditto, 1903, No. 12.

† C. Bugge, *Rep. 2nd Fram Exp.*, No. 22, 1910.

‡ G. S. Rogers, *Ann. N. Y. Ac. Sci.*, xxi, p. 11, 1911. This paper gives a complete bibliography.

§ A. Lacroix, *C. R.*, cl, p. 18, 1910.

|| K. v. Chrustchoff, *T. M. P. M.*, ix, p. 470, 1888. Apparently the promised subsequent papers, including the chemical analyses and discussion, were never published.

¶ F. D. Adams, *N. J. B. B.*, viii, p. 419, 1893; *Can. Geol. Surv., Ann. Rep.* viii, J., p. 96, 1896.

Adirondacks.* The relations of the first are uncertain as the description of the district is incomplete. While having some features in common, the Canadian and Adirondack areas seem to be of a somewhat different character, as augite very largely replaces hypersthene, in Canada the masses are predominantly of anorthosite, and in the Adirondacks augite syenite and similar rocks are common.

It is possible that a district similar to that of India exists in the interior of the State of Bahia, Brazil.

The mineralogical characters which the Norway, Ellesmere Land, Cortlandt, and Ivory Coast regions have in common with that of India are as follows: Hypersthene is the most important and most characteristic mafic mineral in all the districts, and, especially, is the essential mafic mineral in the most silicic types, the granites, quartz monzonites, and quartz diorites. The peculiar pleochroism of this hypersthene seems to be very constant: *a* and *b* being in light red or pink tones (not the ordinary browns or yellows), and *c* very pale green or blue gray. The parting or cleavage parallel to *b*(010) seems to be commonly developed, rather than the normal prismatic cleavage, and schiller inclusions are common.

A "hypersthene-like" pyroxene with very similar pleochroism and low birefringence has been described by J. J. Allan† as occurring in the jacupirangite of the Ice River area in British Columbia. It has an oblique extinction of about 38° , and is considered by him to be a clinohypersthene. It is, however, optically positive, and the analysis, with its low SiO_2 , considerable Al_2O_3 , and high CaO and TiO_2 , indicates that it is really an augite, and that probably the marked pleochroism is due to the presence of the titanium.

A colorless or almost colorless monoclinic augite, with a faint pleochroism similar to that of the hypersthene, is sometimes present, but generally in very small amount. In Norway it seems to be more common. This is generally wanting in the more silicic types. Hornblende begins to appear as silica falls, and is abundant (though less so than the hypersthene), in the most femic types. It is constantly of a brownish-green color, and highly pleochroic in tones of yellow brown and yellow green. Biotite is rare or accessory and quite absent in most of the types.

A soda-lime feldspar is present in all except the most femic types, such as the pyroxenites.‡ It varies in composition from an oligoclase in the granites to a labradorite in the norites. In

* Cf. H. P. Cushing, various papers in A. R. N. Y. St. Mus. and B. G. Soc. Am.

† J. J. Allan, Can. Geol. Surv., Mem. 55, p. 169, 1914.

‡ In these the normative feldspathic molecules have entered the modal hornblende.

some of the districts rocks composed almost wholly of soda-lime feldspar form a large part of the complex. It is worthy of note that a peculiarity of the soda-lime feldspars in the hypersthene rocks of these districts seems to be the frequent absence of twinning lamellæ, so that at first glance some of this feldspar might be taken for orthoclase. This peculiarity is noted independently by Kolderup, Holland, Bugge, Adams, and Rogers, is hinted at by Lacroix, and has been noted in descriptions in the preceding pages. Microcline, or rather anorthoclase with the usual microcline twinning, is a constant component of the more silicic members. Orthoclase seems to be constantly absent.

Ilmenite, or a titaniferous magnetite, is constantly present, even in the most silicic members, and would seem to be the only essentially titanium-bearing mineral in these rocks.

In their chemical characters, also, the hypersthene rocks of the several districts are very similar, as may be seen from a study of the analyses cited in the preceding tables.* In all the districts there is great variation in silicity, SiO_2 , varying from well over 70 per cent to about 50 or even considerably below. The iron oxides are consistently higher than magnesia,† often very considerably so, except in the most femic members, in which the magnesia is largely in excess. A notable amount of lime is always present, even in the most silicic rocks, but in general (except in the most femic members), its amount is not more than enough to satisfy the excess of alumina over alkalis to form anorthite. That is, the lime is wholly salic, whence the prevalence of hypersthene, except in the most femic rocks where it is partly femic, forming the diopside molecule and entering modal hornblende and augite to a much less extent. On the other hand there is never, even in the most silicic rocks, an excess of alumina, when satisfactory analyses are considered. With this is to be correlated the paucity in biotite. The alkalis are rather high and soda dominates largely over potash, except in the most silicic rocks, where the potash increases until its amount is about equal to that of the soda. In the great majority of types titanium is consistently low. Phosphorus is always very low.

All the regions named show these general characters in common, but each possesses certain individual peculiarities in the extension of the series. These peculiarities may be attributed either to initial differences in the composition of the general magma at each; to differences in the extent to which differentiation has progressed; or, as seems probable in some cases, to lack of adequate knowledge of the region.

* Only a few of those representing the other regions are given here.

† The molecular, not the percentage, relations are referred to here and subsequently.

In India the series extends from highly silicic granites through quartz diorites and norites to hornblendic pyroxenites, the intermediate members being rather complex and varied, and some olivinic rocks occur. Anorthosites and peridotites are found in southern India, but their comagmatic and geological relationships to the charnockite series are as yet uncertain. In their hypersthene rocks the west Norway districts are strikingly like the Indian, and Kolderup, who examined sections of the charnockite series types, speaks of many of these as "almost identical" with the Norwegian. But in Norway these are associated with much larger masses of labradorite or andesine anorthosites, pyroxenites are comparatively rare, peridotites are unknown, though there are a few olivine gabbros. There are also present dikes of ilmenite-norite and ilmenitite.

The Ellesmere Land region corresponds remarkably—so far as known—with the Indian, though the series here does not reach so far as an end-member as the pyroxenites. According to Bugge, anorthosites seem to be absent. In the Cortlandt Series the relations in the small areas are complex and many varying types are present. A mica granite without hypersthene is present, but is comparatively unimportant and its relations to the main mass are somewhat uncertain. The chief rocks are norites and pyroxenites, often hornblendic, with subordinate olivine-rich types. There are no anorthosites or ilmenite rocks. At the Ivory Coast the variation closely resembles that of India as pointed out by Lacroix, the types running from hypersthene granite to norite. True pyroxenite has not yet been found, but Lacroix thinks it probable that further search will reveal this type. Anorthosites and peridotites are unknown.

Conclusion.

Thus there are at least five or six comagmatic regions of ancient plutonic rocks which show in common certain peculiar mineralogical and chemical features. Mineralogically the rocks are characterized by the constant abundance of a peculiar hypersthene, with subordinate hornblende of a constant kind, paucity in augite and biotite, prevalence of a soda-microcline along with soda-lime feldspar. In some cases these rocks are associated with anorthosites, and to a much less extent with olivine and ilmenite rocks.

Chemically they are characterized by the dominance of iron oxides over magnesia and lime, the two latter being present in about equal amount; rather high alkalis with soda predominating, and alumina in the majority of the types about

equal to the combined alkalis and lime, and with wide variation in the silicity.

In some respects the rocks of the regions described resemble those of the Ural mountains, but these last carry augite generally instead of hypersthene, olivine and magnetite rocks are common; and chemically they are higher in lime and with magnesia much higher than iron oxides. The range in silica is also much less, the silicity being lower and seldom or never attaining that of the intermediate members of the other series. The resemblance in some respects to and difference from the eastern Canada and Adirondack regions have already been touched on.

It is obvious that the five regions here discussed differ markedly in their essential characters from the usual regions belonging to the so-called subalkalic, calci-alkalic or Pacific tribe. Indeed, so marked is this distinction that Wolff* reckons them with the rocks of his "Arctic tribe," constituted essentially of basalts and basaltic rocks. The peculiar characters brought out in this paper, however, distinguish them clearly from the ordinary basaltic or gabbroic rocks, and such a conjunction is, to my mind, unjustified.

This is not the place for a discussion of the much-mooted question of the Atlantic and Pacific branches. Daly† shows the irrelation of the type of crustal movement to the magmatic character, and I have briefly pointed out‡ the irrationality of referring the many varied and complex types of magma and comagmatic regions to only two contrasted branches. The well-established occurrence in widely diverse parts of the earth of such a group of comagmatic regions as those represented by the charnockite series, with their common very distinctive peculiarities, mineralogical and chemical, which are markedly different from the usual "sub-alkalic" or "Pacific" rocks, constitutes another instance which illustrates the untenability of the doctrine of Harker, Becke and their followers.

Geophysical Laboratory,
Carnegie Institution of Washington,
Washington, D. C., Dec. 12, 1915.

* F. v. Wolff, *Vulkanismus*, i, p. 153, 1914.

† R. A. Daly, *Igneous Rocks*, p. 412, 1914.

‡ H. S. Washington, *C. R.*, xii, *Congr. Geol. Int.*, p. 237, 1914.

ART. XXIII. — *The Determination of Vanadium by Cupferron, $C_6H_5N(ONH_2)NO$; by W. A. TURNER.*

[Contributions from the Kent Chemical Laboratory of Yale Univ.—ccclxxvii.]

THE present paper gives the results of experiments begun nearly two years ago on the determination of vanadium by means of cupferron (the ammonium salt of nitrosophenylhydroxylamine). At that time the actual determination of vanadium by this means was not so much sought as its separation from the element uranium.* A large number of experiments carried out for this purpose failed to reveal the proper conditions for a successful separation of these two elements. However something was learned of the reaction between vanadium and cupferron and it is with this reaction and its application to the estimation of vanadium that the present paper deals.

Vanadium in the form of its soluble vanadate in slightly acid solution (hydrochloric or sulphuric) gives with cupferron a mahogany red precipitate. This reaction is so delicate that it may well be used as a qualitative test for a vanadate. If the solution has a low concentration of vanadium a red coloration instead of a precipitate is obtained. A solution containing 0.000004 gm. vanadium per cubic centimeter gives a distinct coloration. Solutions of much lower concentration do not, in my experience, give the test.

A solution of ammonium metavanadate (prepared by precipitation from a solution of sodium vanadate by means of a saturated solution of ammonium chloride† and then washing until free from chlorides) was used for this work. The metavanadate was dissolved in water by constant stirring and gradual addition of concentrated hydrochloric acid.

To obtain the vanadium content of this solution the volumetric method, which involves a reduction of the vanadate by sulphurous acid and then oxidation by a measured amount of standard $KMnO_4$ solution, was used. There was some inconvenience in applying this method because of the fact that the vanadium solution contained hydrochloric acid, which acted upon the $KMnO_4$, giving too high results. This difficulty was overcome with some degree of success by evaporating the weighed portions of vanadium solution with sulphuric acid to remove the hydrochloric acid and then diluting and carrying out the process above mentioned.

*The use of cupferron for this purpose was suggested by Dr. W. M. Thornton. While this work was in progress two papers by Rodeja have appeared to which reference will later be made.

† Ann. Phys., xcvi, 54, 1831.

In this way the following results were obtained :

TABLE I.

Exp.	Gms. of NH_4VO_3 solution taken	Gms. of V_2O_5 found	Gms. of V_2O_5 per 25 gms. of solution
1	25.9374	0.1714	0.1652
2	25.9846	0.1747	0.1681
3	25.6772	0.1699	0.1654
4	25.9426	0.1727	0.1664

These results not being wholly satisfactory in establishing the vanadium content of the solution, it was decided to try the apparently simple method of evaporating weighed portions of the solution, igniting the residues and weighing the amounts of vanadium pentoxide obtained. In this process also the presence of hydrochloric acid is an inconvenience. The results obtained were too low. It was noted that in the ignition some volatile product was formed which was deposited on the cover and the outer edges of the crucible. It is probable that some of the very volatile oxychloride, VOCl_3 , is formed. An attempt was made to prevent this by evaporating the solution with sulphuric acid and thus remove hydrochloric acid, but under these conditions high results were obtained evidently due to the formation of a not readily decomposable vanadium sulphate. Simple evaporation and ignition of the ammonium vanadate solution was finally again resorted to and by a careful regulation of the heat (the temperature being very gradually increased from the lowest possible flame of a Bunsen burner to the high heat of the Meker burner) the following quite concordant results were obtained :

TABLE II.

Exp.	Gms. NH_4VO_3 solution taken	Gms. of V_2O_5 found	Gms. of V_2O_5 per 25 gms. of solution
5	25.4215	0.1679	0.1651
6	25.4215	0.1680	0.1652
7	25.4215	0.1683	0.1655
8	25.4215	0.1690	0.1662
9	25.4215	0.1681	0.1653
10	25.4215	0.1683	0.1655

The mean of these results was taken as the true value and the standard thus established as : 25 gms. solution \rightleftharpoons 0.1655 gm. V_2O_5 .

The determinations by means of the cupferron solution were carried out as follows:

Portions of about twenty-five cubic centimeters of the metavanadate solution, accurately weighed, were diluted to about 150–200 cm³. The hydrochloric acid present in the metavanadate solution was sufficient for the complete precipitation of the vanadium. Not more than 1 per cent acid content (hydrochloric or sulphuric) is needed. Cupferron solution (6 per cent) prepared according to Baudisch* was then added with stirring until a slight excess was present as shown by the appearance of a white precipitate of nitrosophenylhydroxylamine (formed when cupferron comes in contact with an acid solution). Two or three cubic centimeters in excess are added and the precipitate is filtered on paper without delay and washed with a 1 per cent solution of sulphuric acid containing a little cupferron. The precipitate after being allowed to drain on the filter for a time is transferred with the paper to a platinum crucible, dried, ignited and weighed as vanadium pentoxide.

In this process there are several precautions which should be observed. The precipitate after being filtered on paper is transferred to a large platinum crucible and heated with a small flame to dry the mass and remove volatile substances from the precipitate and paper. This should be done cautiously in order not to produce a heat sufficient to fuse the vanadium oxide. If the attempt is made to hasten the ignition, the carbon of the unburned filter may mingle with the fused vanadium oxide, thus delaying the oxidation of the former, which is ultimately accomplished probably more or less at the expense of the latter. At best some of the oxide is likely to become reduced and must be thoroughly exposed to the action of the air by revolving the crucible held by the tongs in the flame and allowing the fused oxide to flow on the sides. By this means the oxide may be brought to its highest state of oxidation.

An apparently necessary condition for the formation of the vanadium-cupferron precipitate seems to be a slight acidity of the solution. Experiments made in this connection showed that if aqueous solutions of sodium vanadate and of cupferron, both made neutral to litmus, were mixed the resulting solution became alkaline (evidently due to ammonia liberated), no precipitate being formed. This alkalinity must be overcome by addition of acid (hydrochloric or sulphuric) and a slight excess must be used in order to bring about complete precipitation.

The precipitate, transferred to the filter, is washed with a solution containing about ten cubic centimeters of concentrated

* Chem. Zeitung, xxxv, 223, 1911.

sulphuric acid and 1.5 gms. of cupferron per liter. The solutions and wash-liquid used should be cold; that is, their temperature should not exceed 20° C. If the temperature is allowed to rise much above this the precipitate tends to decompose and forms a gummy mass which clogs the pores of the paper and makes filtering almost impossible. The precipitate is ready to filter about as soon as formed and there should be no delay in the filtration and washing. If the precipitate is allowed to remain long on the filter it tends to crack and is then more difficultly washed, while if the process is carried out quickly and without interruption, it is readily filtered and washed.

By this process the following results were obtained:

TABLE III.

Exp.	Gms. NH_4VO_3 solution taken	Gms. of V_2O_5 found	Gms. of V_2O_5 per 25 gms. of solution	
			found	taken
11	25.4236	0.1686	0.1658	0.1655
12	25.4193	0.1685	0.1657	0.1655
13	25.3242	0.1673	0.1652	0.1655
14	25.6816	0.1703	0.1658	0.1655

From the above data it appears that the vanadium in vanadates can be very accurately estimated by means of the cupferron reaction. Investigations are being made into the use of this reagent for the separation of vanadium from other elements, the results of which will appear at an early date.

Recently the statement has been made by Rodeja* that vanadium in the form of vanadates cannot be quantitatively precipitated by cupferron, but that if the vanadate is first reduced to the vanadyl condition a quantitative estimation of the vanadium may then be made. Experiments made according to the rather meager details given in the abstract of this work failed to confirm this statement.

Four portions of a solution of sodium vanadate, two of which were precipitated without reduction and the other two after reduction, gave the following results:

* Abstract Journal of the Am. Chem. Soc., ix, 2201, 2202, 1915. *Anales soc. Espan. fis. quim.*, xii, 305-9, 379-82, 1914.

TABLE IV.

Exp.	Gms. Na_3VO_4 solution taken	Gms. of V_2O_5 found	Gms. of V_2O_5 per 25 gms. of solution
Without Reduction			
15	20.1067	0.0873	0.1085
16	20.4030	0.0882	0.1081
With Reduction			
17	54.1156	0.2300	0.1063
18	46.2709	0.1954	0.1056

The filtrate from Exp. 17 was evaporated and the residue ignited. A solution of this residue gave with cupferron a distinct test for vanadium.

Kent Chemical Laboratory, Yale University.

ART. XXIV.—*Description of a New Genus and Species of Fossil Crab from Port Townsend, Washington*; by MARY J. RATHBUN, Associate in Zoology, United States National Museum.

THE crab described in this paper was presented to the Yale Museum in 1873 by Dr. Thomas T. Minor, a graduate of the University. Although it is from the late Tertiary, the exact horizon is not known, and according to Dr. John C. Merriam, of the University of California, who has kindly examined the specimen, it is impossible even with a fair knowledge of the geology of the region to state its position with certainty.

For the privilege of making the description I am indebted to Prof. Charles Schuchert.

Tribe **BRACHYURA.**

Subtribe **Brachygnatha.**

Superfamily **BRACHYRHYNCHA.**

Family **Goneplacidae.**

BRANCHIOPLAX, gen. nov.

Carapace a little broader than long. Anterior margin arcuate. Orbits of moderate size. Antero-lateral margins dentate and very short, about half as long as postero-lateral margins, which are subparallel, but with the posterior angles rounded. Front not emarginate. Regions well defined, branchial regions swollen dorsally and approximate. Chelipeds unequal, of moderate length, carpus not much broader than long, manus high.

(*Βράγχια*, gills, branchiae, in allusion to the swollen branchial region; *πλαξ*, anything flat and broad, carapace.)

This genus is akin to the recent genus *Eucrate* de Haan* (type, *E. crenata* de Haan, from Japan), of the subfamily Carcinoplacinae, but differs in having an entire front, that is, uninterrupted by a median emargination or by a separate small tooth at the inner angle of the orbit; in the narrower and more oblique orbit; in the shorter antero-lateral margin with only two teeth, and those distant from the orbit; in the after part of the carapace being squarer, the sides subparallel in part instead of constantly converging; in the more areolated carapace and less massive and very unequal chelipeds.

Type of the genus, *Branchioplax washingtoniana*.

As the characters of the ventral surface are not known, it is impossible to assign the genus to its subfamily.

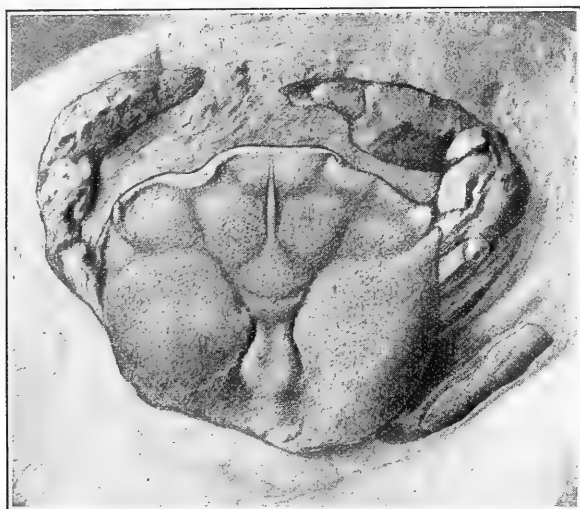
* Fauna Japon., Crust., p. 36, 1835.

BRANCHIOPLAX WASHINGTONIANA, sp. nov.

Type-locality.—Port Townsend, Washington; late Tertiary.

Holotype.—Dorsal view of a single specimen exposed in nodule. Cat. No. 195, Yale University Museum. Presented by Dr. Thomas T. Minor, in 1873. A plastotype or cast of the holotype has been made by Dr. R. S. Bassler for the United States National Museum; Cat. No. 167203.

Measurements.—Approximate. Length of carapace 28, width of carapace 30·7, width of front between the orbits 10·8, fronto-orbital width 17·4, width between the two branchial regions 3·5, length of that part of the merus of the right or



larger cheliped which shows outside the carapace 7, length of carpus 8, width of carpus 8·7, length of palm along upper margin 11·4, length of dactylus (perhaps an underestimate) 8, length of palm of left or smaller cheliped 6 mm.

Of the regions of the carapace, the branchial are the most prominent and are deeply separated from the cardiac; the narrow part of the mesogastric region is bordered by broad, smooth furrows, and is acuminate; from it a very shallow median furrow may be seen leading to, but not crossing, the slightly arcuate upper margin of the front; the middle part of the mesogastric region is faintly outlined; a broad and deep transverse depression between gastric and cardiac regions; hepatic regions distinctly outlined. A shallow, oblique furrow

separates the upper surface of the orbit from that of the front. Surface of carapace granulated, granules coarser on the sides of the branchial regions, absent or scarce in the depressions and on the cardiac region and behind the margin of front and orbit. Edge of front and orbit granulated, granules placed irregularly, not all in one row. Next to the orbit, the antero-lateral margin appears straight and oblique for a distance a little greater than the width of orbit, after which there are two strong projecting teeth, the first being the wider. Behind these teeth the lateral margins are nearly straight and parallel for a way, then curve gradually into the posterior margin, which is broken away from the single specimen.

Details of the chelipeds are not easy to make out. The chelipeds are bent and similarly placed, so that the wrist nearly touches the larger antero-lateral tooth of the carapace; in this position the larger cheliped reaches to a point approximately in line with the middle of the body while the smaller cheliped reaches to the middle of the orbit. Very little of the merus is visible beyond the carapace; the carpus is rounded, without evidence of an inner tooth; the manus is apparently thick, and the movable finger is stout; no prehensile teeth are visible; propodal finger absent from the large cheliped, crushed and indistinct in the small one. Surface of chelipeds granulate, as also of the long merus joints of two ambulatory legs, which are all that is left of those appendages.

ART. XXV.—*Note on a Palæoniscid Fish from a Permian Formation in South Dakota*; by L. HUSSAKOF.

THROUGH the kindness of President C. C. O'Harra of the South Dakota School of Mines, I have recently had the privilege of examining two fishes from a Permian formation in the Black Hills region of South Dakota. No fish remains had previously been found in this formation, so that the find is of interest as promising to add a new locality for Permian fishes to the two at present known in America—those in Illinois, and in Texas-Indian Territory.

The fishes thus far collected are all imperfect, the two here described being the best ones found. One is the greater portion of a fish, the other merely a fragment of the body of a larger individual.

The formation and locality are described by President O'Harra as follows:

"The fishes were found in a quarry three miles northwest of Rapid City, South Dakota, in the Minnekahta limestone,* where the rock is being extracted for road metal and miscellaneous structural purposes. The quarry is under control of the Northwestern Quarry Co. My attention was called to the fish by Mr. Albert Halley, one of the interested members, through whom I secured the loan of the specimen from Mr. L. E. Parrish, who owns it.

"The Minnekahta limestone throughout the Black Hills region is of fairly uniform character and thickness. At this particular point it is approximately fifty feet and is made up of a nearly uniform greenish gray to purplish limestone which when observed from a distance seems quite massive, but near at hand shows a thinly bedded or flaggy nature. Near the middle of the formation this flaggy condition is more pronounced and generally shows somewhat distinctly because of more rapid weathering. In this particular quarry, the lower beds are inclined to be fairly massive and the stone obtained from them has served to a little extent as a local building material.

"The fish-bearing layer is in the lower part, approximately thirty-five feet below the top of the formation. There is nothing especially different in the general nature of the slabs containing the fossils and their presence in the quarry cannot be detected except as the surface bearing them is exposed."

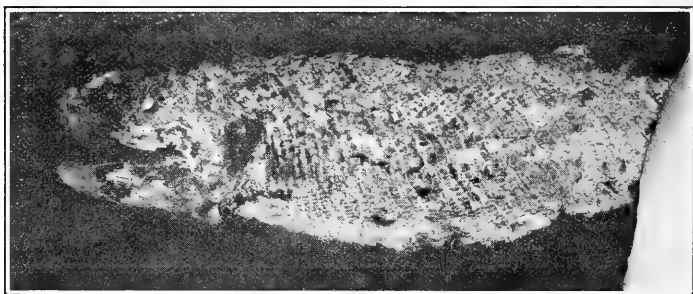
There are three previous records of fossil fishes from South Dakota, which may here be briefly referred to. In 1878,†

* Generally regarded as Permian: Bailey Willis, Index to the Stratigraphy of North America, Professional Paper 71, U. S. Geol. Survey, 1912, pp. 495-496.

† Cope, E. D., Descriptions of fishes from the Cretaceous and Tertiary Deposits west of the Mississippi River, Bull. 4, U. S. Geol. and Geogr. Surv. Territories, pp. 67-77, 1878.

Cope described seven species, representing five genera, from a Cretaceous horizon, collected by the Hayden Survey of the Territories. They included two new genera, *Trienaspis* and *Ichthyotringa*; and the species, as a whole, showed a marked resemblance to the Cretaceous fauna of Mount Lebanon. In 1891,* Cope described five species from the Black Hills region, three of them representing new genera. One form was a new species of *Mioplosus*, a genus previously known only from the

FIG. 1.



A palæoniscid fish from the Minnekahta limestone (Permian), near Rapid City, S. D. $\times 3/5$.

Green River shales of Wyoming. This fact, and also the absence of Cretaceous forms, led Cope to believe that the specimens were from a Tertiary horizon; and the resemblance of the matrix to that of the White River formation, led to the conclusion that the horizon was probably Oligocene. No further light has ever been thrown on these species, and no additional specimens have, to my knowledge, been obtained.

A third record of South Dakota fishes was given in a short paper by C. R. Eastman, in 1899.† He figured several specimens from a Jurassic formation in the Black Hills region, among which he recognized two species, named by him *Pholidophorus americanus* and *Amiopsis? dartoni*. No other examples of these species have since been obtained.

The fishes from the Minnekahta limestone differ from all previously described and are of an earlier age, namely, Permian.

Description of specimens.—The better of the two specimens is a fish lacking the caudal extremity, and without any of the

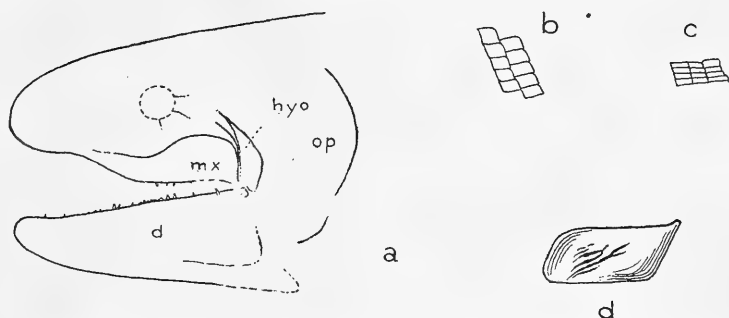
* Cope, E. D., On some fishes from South Dakota, Amer. Naturalist, xxv, 654-658, 1891.

† Eastman, C. R., Jurassic fishes from [the] Black Hills of South Dakota, Bull. Geol. Soc. Amer., x, 397-408, pls. 45-48, 1899.

fins (fig. 1). It measures 13.6^{cm} in length as far as preserved, and when complete must have been a fish of about 21^{cm}. An angular elevation on the upper side near the posterior extremity of the specimen apparently indicates the position of the dorsal fin.

It is plain that the fish belongs to the family *Palæoniscidae*. It is gracefully fusiform, its depth somewhat less than the length of the head, and contained about five times in the estimated total length. The maxilla is of the usual palæoniscid

FIG. 2.



Details of head and scales; natural size, except *d*, which is $\times 4$. *a*, Head traced from the specimen shown in fig. 1: *d*, dentary; *hyo*, hyomandibular; *mx*, maxilla; *op*, operculum. *b*, Scales from anterior portion of flank a little below the middle. *c*, Narrow scales from near ventral margin. *d*, Scale, $\times 4$, to show ornamentation; taken from the second of the two specimens.

form, consisting of a subrectangular plate with the lower anterior angle drawn out into a narrow, sub-ocular process. The mandible is rather strong. It is armed with short, stout, widely spaced laniaries, in the spaces between which are very small, blunt teeth, irregularly spaced. The hyomandibular is inclined forward. The eye is placed farther back than in *Palæoniscus*. The scales behind the operculum are not deepened. The flank scales are as broad as deep, and in some places, even broader than deep. The ventral scales are very narrow, their width twice or more their depth. The ornamentation of the scales can be made out in some of them; it consists of fine parallel lines along the anterior and posterior margins, and a number of coarser, more or less broken and branching lines extending diagonally across the scale. The ornamentation of the cranial plates is not shown.

The second specimen consists of a patch of flank scales from the region near the anal fin. It adds only one or two facts to

what may be learned from the other specimen. In the first place, it represents a larger fish, proving that the species reached a length of at least 35 or 40^{cm}. Secondly, it retains a small portion of the base of the anal fin; this is composed of numerous segmented, closely crowded rays. The enlarged figure of a scale showing the ornamentation (fig. 2*d*) was drawn from this specimen.

Relationships.—It is obvious that the specimens represent a palæoniscid belonging to one of the later, more specialized genera of the family. This is shown by the large size of the fish, the stout mandible, strong dentition and the extremely narrow ventral scales. But it is impossible to identify the genus since the fins are lacking, and the ornamentation of the head bones is not shown. On the whole, the fish seems closest to *Acrolepis*,* a genus represented by several species in the Carboniferous and Permian of Europe and South Africa, but not previously known from North America. Doubtless complete specimens displaying all the characters of the species will some day be found, and the naming of the species may best be deferred until then.

American Museum of Natural History,
New York City.

* Woodward, A. S., Catalog of Fossil Fishes in the British Museum, Part II, 501.

ART. XXVI.—*On a Gallium-Indium Alloy*; by PHILIP E. BROWNING and HORACE S. UHLER.

[Contribution from the Kent Chemical and the Sloane Physical Laboratories of Yale University.]

A FEW months ago Mr. F. G. McCutcheon, chemist of the Bartlesville Zinc Company, observed some mercury-like globules upon the surface of a leady residue from the distillation of zinc. The appearance of these globules seemed to be due to the fact that the residue had been stored away in a warm place, and the phenomenon suggested to the observer the subjection of the residue to a sweating process. This treatment resulted in a more abundant separation of the peculiar material, which, from the character of its source and its low melting point, suggested the element gallium. It proved to be essentially an alloy of that element with indium.*

Through the kindness of the manager, Mr. K. Stock, and the chemist of the Company, we have been supplied with several grams of the alloy and a considerable amount of the leady residue. Rough analyses of these products show the gallium-indium alloy to contain about 10 per cent of indium, with small amounts of zinc and lead, and spectrographic traces of copper and silver. The leady residue contains about 95.6 per cent of lead, a fraction of 1 per cent of copper, about 3 per cent of gallium and indium together, and about 1.2 per cent of zinc.

The alloy is not very vigorously attacked by the common acids, especially by nitric acid, nor by potassium or sodium hydroxide, although all of these reagents act upon it more or less, especially upon warming. Aqua regia dissolves it very readily. From a solution of the alloy the hydroxides of gallium and indium may be precipitated together by ammonium hydroxide in the presence of ammonium chloride,—a method of separation from zinc first worked out by Lecoq de Boisbaudran.†

Other procedures suggested by him are the separation of gallium from indium by treating a solution containing them with potassium or sodium hydroxide in excess, which dissolves the gallium hydroxide,‡—a method followed by us with fair success; and the separation from aluminium, chromium and beryllium, elements which form a group with gallium because their hydroxides are not only precipitated by ammonium hydroxide in the presence of ammonium chloride, but are soluble in sodium or potassium hydroxide, the separation being accomplished by making the alkaline solution of the hydroxides

* Hillebrand and Scherrer, *Jour. Indust. and Eng. Chem.*, viii, 225. (This article appeared after our paper had gone to press—authors.)

† *Compt. rend. (Paris)*, xciv, 1628.

‡ *Ibid.*, xciv, 410.

strongly acid with hydrochloric acid and precipitating as the ferrocyanide.*

Gallium may be precipitated electrolytically by passing a current through an alkaline solution containing the element.† By this method gallium may be separated from indium, as our experiments have shown, practically no spectrographic evidence of indium being found in the product.

A fractional crystallization of the ammonium-gallium and the ammonium-indium alums has resulted after six crystallizations in a marked separation, the ammonium-gallium, at the less soluble end of the series, giving no flame test for indium, while the ammonium-indium alum, at the more soluble end, gave abundant evidence of indium in the flame. This method will be studied more in detail with the substitution of other alkalies for ammonium. The fact that gallium and indium are alum-forming elements makes this method promising for the removal of the non alum-forming elements which may be associated with them, and this possibility also will be further investigated.

The results obtained by purely physical processes will now be presented. Since no data on the boiling point of gallium could be found the following experiments were performed. A transparent silica tube, of internal diameter 0.7^{cm} and about 30^{cm} long, was first sealed off round at one end by fusion in an oxygen-illuminating gas flame. After introducing about 0.4 cm³ of the alloy, the tube was joined by sealing-wax to a long glass tube which led to a Gaede rotary mercury pump. The fused end of the tube where the alloy was situated was heated red hot for three hours with an ordinary blast flame while the pump was kept in action and the sealing wax was cooled by running water. The silica tube was nearly horizontal and the pressure in the glass tube was less than 0.0005^{mm}. This process removed all the zinc and other elements of relatively low boiling points but the gallium-indium alloy showed no signs of boiling. A bulb made from a silica test-tube was then fused to the end of a new quartz tube and the liquid globule which had not distilled in the previous heating was dropped into the bulb. While the pump and ordinary blast flame were kept going the bulb was also heated very cautiously with an oxygen-illuminating gas flame. The alloy then disintegrated with violence, shooting very fine particles of the liquid and a gray powder for a distance of 15^{cm} along the axis of the tube. Even when the silica bulb was dazzling white and began to cave in there remained a globule of metal which

* Compt. rend., xciv, 1228, 1439.

† Schucht. Chem. Ztg. (1880), 292; Erlich, *ibid.* (1885), 78; Kunert, *ibid.* (1885), 1826.

did not appear to diminish in mass on continued, intense local heating. This globule was subsequently burned in the carbon arc and the spectrogram showed that it was nearly pure gallium. As might be expected from the tabulated boiling points (at 76^{cm} pressure) most of the copper (b. p. 2310°C.) had not been driven off. Not a trace of lead (b. p. 1525°C.) could be detected. The amount of indium remaining was very small. It seems safe to conclude that the boiling point *in vacuo* of pure gallium is greater than 1600°C. and that prolonged heating in a suitable furnace at a temperature of about 1800°C. would effect a complete separation of indium from the alloy.

The density of the specimen was found to be 5.91 grams per cubic centimeter at 20°C. , the value given in the standard tables being 5.95. The smaller value cannot be accounted for on the ground of contamination with silicon from the walls of the tube because this hypothesis is not consistent with the spectroscopic evidence. The melting point of the globule was not absolutely sharp but the metal consistently fell through a platinum ring, of smaller diameter than the solid disc, at a temperature of 29.5°C. As recorded by other observers, the metal remained liquid at 0°C. and showed no signs of congealing at the expiration of several hours. It may be of interest to note that when, on different occasions, small globules of the fairly pure metal and very impure alloy were partially volatilized in the electric arc, there usually remained on the positive carbon a grayish white, vitreous mass having a definite crystalline structure.

Notwithstanding the fact that a thorough investigation of the spectroscopic properties of gallium is now in progress, it may not be premature to record the results already obtained in the process of general orientation. The alloy was volatilized in a direct current arc (110 volt mains) with regraphitized Acheson graphite electrodes. The spectrograph contains an excellent concave grating (by Anderson) of 1 meter radius of curvature and is an improved form of the instrument designed and made by one of us in the year 1904.* The dispersion is such that 1^{mm} includes, on the average, 25.25 \AA in the first order. Since the camera covers the interval from 2000 \AA to 7600 \AA , the identification of ultra-violet lines is facilitated by the superposition on the first order of the second and third orders. The films used were made to order through the kindness of Dr. C. E. K. Mees, and they are easily sensitive from 2000 \AA to 7500 \AA . The wave-lengths given below are highly tentative. The first negative of the alloy (taken January 22, 1916) brought out the following facts which have been sub-

* See "Atlas of Absorption Spectra" by H. S. Uhler and R. W. Wood, Carnegie Institution of Washington, Publication No. 71, May, 1907.

sequently verified by numerous exposures with much purer material in the crater of the arc. There is a new band spectrum due either to gallium or to gallium oxide (but very probably due to the gallium molecule) the wave-lengths of the heads of which are roughly 3889, 3778, 3677, 3586 (?), 3495, and 3415. The head near 3586 is partially concealed by the 3590 band usually ascribed to cyanogen. The band commencing at 3889 is by far the strongest and has a very sharp, well-defined edge. The intensity of the successive bands decreases as the wave-length becomes smaller. Moreover, the heads of the fainter bands are not sharp, but this may be due to underexposure. On the other hand, the individual bands shade off toward the red. The dispersion and resolving power are so low that there seems to be no separation of the bands into fine lines. These bands extend a relatively long distance and appear, at first glance, to form a continuous background to the entire region from 3415 to 4000. The cyanogen bands, on the contrary, show fine line structure even in the first order.

A series of eleven lines occurs between 3890 and 4030. These lines are comparatively fine and close together, and separate more and more as the frequency increases. The group probably constitutes the heads of a set of fine bands which are narrow and shade off toward the less refrangible side. Various careful tests show that indium is not responsible for the production of any of the bands mentioned above. Both sets of bands seem to be best developed when the gallium is first heated in the arc and the metallic vapor is evolved copiously.

In addition to the lines recorded by earlier investigators, the negatives of the purest specimens of gallium which we have so far been able to produce contain lines at $\lambda\lambda$ 2259, 2294, 2338, 2371, and 2418. These lines have the character of the heretofore known gallium lines and they certainly do not pertain to any of the impurities such as copper, indium, lead, silver, tin, zinc, etc. An attempt to discover a hypothetical ultra-violet absorption spectrum of the vapor of gallium failed. It is highly probable that this negative result was due to the fact that it was not feasible to heat the large silica bulb used to a higher temperature than was produced by the flame of a Meker burner. As soon as possible the wave-lengths of the gallium lines will be accurately determined by means of a 21 ft. grating so that the constants of the series formula may be calculated independently of the analogous data for aluminum, thallium, indium, etc.

The authors wish to make acknowledgment to Dr. W. F. Hillebrand of the Bureau of Standards, who first called their attention to the existence of this alloy.

Yale University, New Haven, Conn., March, 1916.

ART. XXVII.—*Studies of Brazilian Favas*; by OLIVER C. FARRINGTON.

AMONG the exhibits of the Brazilian Commission in the Mines Building at the Louisiana Purchase Exposition was one of minerals which are found accompanying the diamond in the state of Minas Geraes, Brazil. All the minerals were in the form of rolled pebbles and included in addition to readily recognizable specimens of tourmaline, rutile and cyanite, a number of less easily identified species known under the general name of favas. This term, derived from the Portuguese word for beans, is, as is well known, a common appellation among the diamond miners for minerals resembling a bean in shape and size. The entire series of minerals and favas was, through the kindness of the Brazilian Commission, presented, at the close of the Exposition, to the Field Museum of Natural History. Among the series one group of pebbles was labelled goyazite, and on account of the rarity of this mineral, special examination of these pebbles was made by the writer. They seemed sufficiently uniform in appearance to belong to a single species, since in color, shape and texture they appeared similar. There were several score of the pebbles included in the lot, their color being brownish yellow, their longest diameters ranging from 3 to 10 mm. and their diaphaneity being none. On closer investigation the pebbles were found to be less uniform than appeared at first sight, the first lack of uniformity noted being one of specific gravity. Some favas were found to have a specific gravity of about 3 and others of about 4. A difference in the luster of the surface was also found to accompany the difference in specific gravity, the smoother, more lustrous pebbles or favas being found to be lighter in specific weight than the duller ones. Qualitative chemical examination of the heavier, dull favas showed that they were TiO_2 , favas such as were first noted by Gorceix,* and later described by Hussak.† They consisted of TiO_2 with a little water. They were infusible but turned dark on heating. Heated in the closed tube they also turned dark and gave off a little neutral water. Determinations of specific gravity gave results ranging from 3.97 to 4.08. A quantitative determination of water gave 0.6 per cent. While this form of hydrous oxide of titanium probably cannot be regarded as a distinct species, it seems to the writer that it is a sufficiently definite occurrence to make a varietal name for it desirable. The quantity of

* Bull. Soc. Min., vii, 179, 1884.

† Tsch. Min. Petr. Mitth., xviii, p. 335.

water present is small but is characteristic and easily detected. This constituent thus makes a distinguishing character between these favas and rutile or any other of the titanium oxides. The writer therefore proposes the term *paredrite* from the Greek *παρεδρος*, an associate, for these favas. The term refers to the fact that they are companions of the diamond.

The favas of brighter luster and lower specific gravity in the so-called "goyazite" were found to be for the most part easily fusible B. B. Generally also they gave a green flame, indicating the presence of barium or phosphoric acid or both. They also generally gave off acid water in the closed tube. These properties indicated that the pebbles belonged to the group of phosphate favas described by Hussak;* although Hussak unfortunately gave no blowpipe characters. They were only slightly decomposed by HCl, but after fusion with Na_2CO_3 were readily and completely dissolved to a golden yellow solution. In order to still further determine the characters of these pebbles, quantitative analyses were made of three of them by Mr. H. W. Nichols with results as follows :

	1	2	3
P_2O_5 -----	18.33	22.56	31.62
Al_2O_3 -----	40.56	29.98	29.87
Fe_2O_3 -----	2.30	2.23	2.00
BaO -----	13.84	21.48	20.61
CaO -----	1.81	1.95	0.13
MgO -----		1.58	
MnO -----		tr.	
Na_2O -----	3.75	4.23	0.74
SiO_2 -----	3.54	2.22	
SO_3 -----		1.31	
H_2O -----	14.89	12.31	13.67
F-----	0.40		1.77
Moisture-----	0.65		0.26
	<hr/>	<hr/>	<hr/>
O = F_2 -----	100.07	99.85	100.67
	0.17		0.74
	<hr/>	<hr/>	<hr/>
	99.90		99.93
G =-----	2.99	3.10	3.17

The analyses show that these favas are related in composition to the mineral gorceixite described by Hussak.† He deduced the formula $\text{BaO}(\text{Ca}, \text{Ce}).2\text{Al}_2\text{O}_3.\text{P}_2\text{O}_5.5\text{H}_2\text{O}$ for this mineral from the following analysis, the analysis having been calculated to 100 after deduction of SiO_2 , Fe_2O_3 and TiO_2 :

* Tsch. Min. u. Petr. Mitth., xxv, 334-335, 1906.

† Loc. cit.

	Analysis (mean of two)		Ratio		Theory	Ratio
P_2O_5 -----	24.00		.1671	1.04	.24.09	1
Al_2O_3 -----	38.12		.3737	2.32	34.60	2
BaO -----	16.68	} 21.94	.1087			
CaO -----	3.14		.0561	1	26.04	1
CeO -----	2.12		.0136			
H_2O -----	15.94		.8855	5.49	15.27	5
	<hr/>				<hr/>	
	100.00				100.00	

G = 3.10

If, following the example of Hussak, from the analysis of Fava No. 1 the percentages of Fe_2O_3 and SiO_2 be deducted and the remainder be calculated to 100 per cent, the result with ratios is as follows :

P_2O_5 -----	19.61	.138		.70
Al_2O_3 -----	43.71	.429		2.19
BaO -----	14.81	.097	} .196	
CaO -----	1.94	.034		1.00
Na_2O -----	4.01	.065		
H_2O -----	15.92	.885		4.51
	<hr/>	<hr/>		<hr/>
	100.00			

While these ratios are not quite identical to those of gorceixite they seem to show a composition sufficiently near it to warrant regarding this fava as composed of that mineral.

The analysis of Fava No. 2 seems to show such a complex composition that it is impossible to distinguish any primary minerals. This fava was evidently a mixture.

The analysis of Fava No. 3 reduced to ratios gave the following :

		Ratio		
P_2O_5 -----	31.62	0.226		1.52
Al_2O_3 -----	29.87	0.292	} 0.305	
Fe_2O_3 -----	2.00	0.013		2.06
BaO -----	20.61	0.134		
CaO -----	0.13	0.002	} 0.148	1.00
Na_2O -----	0.74	0.012		
H_2O -----	13.67	1.519	} 1.612	10.89
F -----	1.77	0.093		
Moisture ----	0.26			
	<hr/>			
	100.67			

It is evident that this fava is too high in phosphoric acid and fluorine to be referred to gorceixite. In a general way its

composition suggests that of the mineral hamlinite with barium replacing strontium, but the ratios do not seem to warrant identifying the two minerals. The ratios give the formula: $2\text{BaO} \cdot 4\text{Al}_2\text{O}_3 \cdot 3\text{P}_2\text{O}_5 \cdot 11\text{H}_2\text{O}$, which written in the form of a normal phosphate becomes



Calculating the Na_2O and CaO of the analysis as BaO , reckoning F as H_2O , omitting Fe_2O_3 and calculating to 100, the percentages found by the analysis and calculated on this formula compare as follows:

	Calc.	Found
BaO	22.90	23.06
Al_2O_3	30.51	30.24
P_2O_5	31.81	32.00
H_2O	14.78	14.70
	<hr/> 100.00	<hr/> 100.00

A mineral phosphate of this formula has not before been observed and it may be that a new mineral species should here be recognized, but owing to the lack of crystal form and the possibility that the substance may be a mixture, it would seem to the writer advisable to obtain confirmatory evidence before assigning to it a specific character. The substance of this fava was tough, apparently homogeneous and cryptocrystalline. It fused at 3 with swelling to a white enamel and gave off acid water in a closed tube. Of its optical properties nothing can be stated since, unfortunately, all the substance of the fava was used for the chemical analysis.

So far as analyses indicated, no favas in the lot corresponded in composition to goyazite. It will be remembered that Schaller* urged that Damour's goyazite was in reality hamlinite. One of Schaller's reasons for this conclusion was a doubt expressed by Hartley as to the accuracy of the method employed by Damour for separating Al_2O_3 from P_2O_5 in an analysis of plumbogummite made by Damour in 1840. Damour's analysis of goyazite was made in 1884, and even if the same method of analysis was employed in the two cases, it does not seem to the writer certain that it was especially defective. While the occurrence of a hydrous calcium aluminum phosphate of the composition described by Damour evidently needs confirmation, the present evidence hardly seems to the writer sufficient for regarding goyazite and hamlinite the same. If instead of comparing the similarities of the two

* This Journal (4), xxxii, 359, 1911.

minerals as was done by Schaller, the *differences* be compared, the following appear :

Differences between goyazite and hamlinite.

	Goyazite	Hamlinite
Percent P_2O_5 -----	14.87	20.92
“ Al_2O_3 -----	50.66	32.30
“ H_2O -----	16.67	12.00
“ F-----	0.00	1.93
	Infusible	Fusibility 4
	Not attacked by acids.	Slowly soluble in acids.

Schaller has also suggested* that hamlinite, plumbogummite, gorceixite and florencite form a single group of phosphates having the type formula $[R'''(OH)_2]_6R''[R'PO_4]_2[R''(PO_4)_2]$ thus making the formula of gorceixite $[Al(OH)_2]_6Ba.[HPO_4]_2[Ba(PO_4)_2]$. If the percentages given by this formula be compared with those obtained by analysis the discrepancy seems to the writer too great to favor the acceptance of this view. Taking the mean of Hussak's two analyses of gorceixite as reduced to 100 per cent by him and comparing the percentages with those required by Schaller's formula the result is as follows :

	Mean of Hussak's Analyses	Schaller's Formula
P_2O_5 -----	24.00	27.76
Al_2O_3 -----	38.12	29.91
$BaO(Ca,Ce)$ -----	21.94	30.01
H_2O -----	15.94	12.32
	100.00	100.00

Unless later analyses should give different results, Hussak's formula for gorceixite, therefore, seems preferable. On the other hand it may be noted that Hussak's formula for hamlinite, $2SrO.3Al_2O_3.2P_2O_5.5H_2O$, gives too low a percentage of water and also fails to take note of the content of fluorine in that mineral. The percentage of water and fluorine obtained by Penfield in his analysis of hamlinite was 13.93 per cent and of water by Florence in his analysis 14.01 per cent. Yet the percentage of water required by Hussak's formula is only 10.14 per cent.

One of the favas of the lot obtained from Brazil differed from those previously described in being nearly infusible and turning black B. B. It also gave no characteristic flame color.

* Loc. cit., p. 364.

In the closed tube it decrepitated and gave off water. In luster and specific gravity it corresponded closely to the other favas and its color was light ochreous yellow. After fusion with Na_2CO_3 this fava dissolved easily in HCl to a yellow solution. Analysis of this by Mr. H. W. Nichols gave the following result :

Al_2O_3 -----	61.67
Fe_2O_3 -----	4.37
BaO -----	2.66
SiO_2 -----	10.40
SO_3 -----	0.96
P_2O_5 -----	0.76
H_2O -----	17.66
Moisture -----	1.60
	<hr/>
	100.08

The mineral is thus seen to be essentially hydrous oxide of aluminium. Regarding alumina and water as the essential ingredients and calculating to 100, the analysis gives :

Al_2O_3 -----	77.74
H_2O -----	22.26
	<hr/>
	100.00

This corresponds closely to the formula $2\text{Al}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$, the percentages of which are :

Al_2O_3 -----	79.1
H_2O -----	20.9
	<hr/>
	100.00

Here again a new mineral is perhaps indicated, but owing to the impurities of the material the writer is not inclined to urge this conclusion. The chief result which seems to the writer to be indicated by his investigation of this group of favas, is that even among favas closely resembling each other in color, texture, luster and size there may exist substances of very different chemical composition. It is probable that a similarity in specific gravity was the chief agent in bringing into close association substances of such varying composition.

Field Museum of Natural History,
Chicago, Ill.

ARTHUR WILLIAMS WRIGHT.

PROFESSOR ARTHUR WILLIAMS WRIGHT, of Yale University, died at his home in New Haven, Conn., on December 19, 1915. He was born on September 8, 1836, in Lebanon, Conn., where his father, Jesse Wright, at one time a member of the Connecticut House of Representatives, served as justice of the peace, selectman, and a member of the school board. Samuel Wright, who settled in Springfield, Mass., in 1639, was his earliest paternal ancestor in this country. His mother was Harriet, daughter of William Williams and a descendant of Robert Williams, who came to this country from England in 1637, settling at Roxbury, Mass.

He received his early education in his native town, preparing for college, under William Kinne, at Canterbury. His career as an undergraduate at Yale College was a distinguished one. He not only achieved notable successes as a scholar in mathematics and astronomy, the studies of his predilection, and in Latin, also, but he was prominent in undergraduate social life. A life-long love for music naturally led him to identify himself with the musical organizations of his time, and a critical knowledge of music, including an enviable skill in performance, added largely to the pleasures of his later and more leisurely life.

After graduation with the class of 1859, he continued his studies at Yale, specializing in mathematics and science, and in 1861 he received the degree of Ph.D., the earliest award of this degree in course in this country. From this time, until his retirement from active work in 1906, his life was identified with Yale except for a period in 1868-1869, when he studied at Heidelberg and at Berlin, and the three years 1869-1872, during which he held a professorship of physics and chemistry at Williams College.

His connection with the Yale Faculty began in 1863 when he was appointed tutor, teaching Latin for three years and natural philosophy from 1866 to 1868. It is also interesting to note that while tutor he pursued the study of law and was admitted to the bar in 1866 though he never practiced. In 1872 he returned to Yale from Williams College to be professor of molecular physics and chemistry. This chair (to which he

was appointed in 1871) he held until 1887, when he was relieved of the responsibility for the chemistry and the title of his chair was changed to "Professor of Experimental Physics."

One of Professor Wright's most distinguished services to the University, and indeed to the teaching of science in America, was the early recognition that the practice of combining professorships of physics and of chemistry had ceased to be either economical or possible. It was under his stimulus and activity that the first Sloane Laboratory of Yale College—the first structure in the country devoted exclusively to the work of a physical laboratory in the modern sense—was designed and constructed. This was completed in 1883, and henceforth he was able to carry on the work of instruction and investigation under the most favorable conditions, vastly different from those previously existing for him in the time-honored Chemical Laboratory of the elder Silliman. It may be added that this Sloane Laboratory also contained the study and lecture room of Professor J. Willard Gibbs, whose contributions to physical sciences have made it celebrated for all time.

The greater portion of Professor Wright's scientific work found its first publication in this Journal. These contributions are not merely important in substance; they are also characterized by unusual excellence of form and clarity of statement. His fertility in ideas, his full knowledge of the literature of his subject and, not the least, his rare manual dexterity, together enabled him to make a distinguished record as a physical investigator. A short review of the papers, published in this Journal, will prove of interest; references to them will be found in the bibliography which closes this notice.

An early paper, published in 1870, was entitled "On a peculiar form of the discharge between the poles of the electrical machine." This paper describes the glow produced upon the positive ball in an active electrical machine and the conditions under which it may be produced. The striking fact that each portion of this luminous surface can be regarded as due to the effect of a point area on the negative ball, as proved by sharp geometric shadows formed by minute obstacles anywhere within the region between the conductors, is quite new and it affords a particularly beautiful method of determining the shape and position of the lines of force. This investigation was followed by another, "On certain forms of the electrical discharge in air," which contains extensions of experimental methods and results attaching to the positive glow described in the previous paper.

"A description of a simple apparatus for the production of ozone," was followed by two studies of the chemical action of ozone. The first of these—"On the action of ozone upon vulcanized caoutchouc" (1872)—calls attention to the cause of the deterioration of the insulating properties of vulcanite and gave means of correcting the fault. The second paper is entitled, "On the oxidation of alcohol and ether by ozone," and is an application of his ozone apparatus to the chemical investigation indicated in the title.

In the same year Professor Wright published two papers on the Zodiacal light and a note on his observations concerning the polarization of the light of Coggia's Comet. In the first of these papers the question of the polarization of the Zodiacal light, even to a fair determination of the ratio of polarized light to unmodified light, seems to have been definitively settled by the skillful use of a polariscope of his own design. So, also, his second paper, on the spectrum of the Zodiacal light, appears to have decided once for all a discussion which had occupied many observers.

A series of five papers of great interest follow, on the gaseous contents of meteoric irons and stones. In the first of these he reviews the known results of the investigations upon the occluded gases of meteoric irons, quoting Professor Graham and Professor J. W. Mallett. In his own investigations, the material came for the most part from the collection in the possession of Yale University. His conclusions in this first paper were that no one of the several irons which he studied gave any spectroscopic evidences of unknown elements. The second paper is a brief one upon the gases derived from the meteorite of February 12th, 1875, presented as a note preliminary to a further study.

In the following paper entitled "Examination of gases from the meteorite of February 12, 1875," Professor Wright gives a thorough review of the gaseous contents of this meteorite. It appears to be the first stony meteorite thus investigated and the results are of great importance; they not only show the presence of gases occluded in stony meteorites but also prove that they are distinguished by having oxides of carbon as their characteristic gases, instead of hydrogen. He points out the bearing of these observations upon the peculiar spectra of comets and as a support of the meteoric theory of comets.

In 1876 Professor Wright continued these important investigations, extending them to a considerable number of stony meteorites of known origin. The earlier conclusion that these stony meteorites are characterized by a large amount of occluded carbon compounds was abundantly verified, and the last paper contains a long discussion concerning the bearing of these

observations on the current theory of comets. This terminates the series of papers on occluded gases in meteorites, but it is interesting to note that the mastery of the problems involved served him in an admirable piece of work five years later (1881). The paper—"On the gaseous substances contained in the smoky quartz of Branchville, Conn."—is sufficiently defined by its title, but the skill and success with which the investigation was carried out and the results presented makes the article a model worthy of careful study.

In 1877 Professor Wright published two important papers on the deposition of metallic films by the cathode discharge in exhausted tubes. A clear description of the technique of the process and of the physical properties of a large number of metals thus treated makes the papers of unusual interest. The intrinsic value of his method has proved so great that it is quite probable that the name of the author is more widely known from these scientific contributions than from any others published during his long and active life.

In the foregoing review of the scientific work of Professor Wright there has been no effort to do more than sketch the contents of the papers of chief importance; a large number of notes and minor contributions to science have been passed over. It would hardly be just, however, to fail to note his activities in X-ray experiments. At a time when Röntgen's discovery was hardly more than a rumor and the greater number of physicists, perhaps somewhat skeptically, were awaiting more definite descriptions of methods and results, Professor Wright immediately applied the test of experiment and secured the first of these photographs made in this country. This showed in a very striking way his command of all the resources of his science at the time; nor did he stop with a mere verification of the most wonderful features of the phenomena. He made many studies of the nature of the radiations and their reactions on various forms of matter, but, like other contemporary investigations, the results were hardly more than negative and he published them only in a preliminary paper (1896) on the subject.

This short review of the more important scientific work of Professor Wright, which was published and is attainable by everybody, does not by any means exhaust the list of his activities. His observations on the polarization of the solar corona made in Colorado on the occasion of the solar eclipse of July 29, 1878, were among the most important and conclusive up to that time. So, too, at a later date (1888) he aided the Government, as a member of a committee appointed by the National Academy of Sciences, in fixing the standards for polariscopic determinations of sugars at the National Custom Houses. This

is interesting as having been one of the comparatively few occasions in which the Government turned to the National Academy for scientific advice. Another work of public character was performed in 1887, when he served as chairman of the committee of weighing on the Assay Commission to test the weight and fineness of the gold and silver coins at the United States mint in Philadelphia. Further he was, from 1881 to 1886, an adviser of the Government Signal Service, but what he there accomplished has not been specifically published as far as known to the present writer.

Of work, important, but of a different character from that already mentioned, were his labors on the two editions of Webster's Dictionary of 1864 and 1890. In the revision of 1864 he acted as general collaborator, assisting in the preparation of the manuscript for the press, the revision of definitions, especially those of scientific and technical subjects, and in reading the proofs. He also prepared for this edition the articles on "Orthography" and the "Rules" for spelling certain classes of words, and assisted in the revision of the list of "Arbitrary Signs used in Writing and Printing." In the edition of 1890 he gave his attention especially to the definitions in chemistry and physics. Professor Wright also prepared a series of summaries on "Scientific Progress" published in the *International Review* in 1876 and 1877.

Professor Wright was elected a member of the National Academy of Sciences in 1881; he was also a Fellow of the Royal Astronomical Society of Great Britain; a member of the American Philosophical Society; of the Connecticut Academy of Sciences; the American Metrological Society; the New York Academy of Sciences and other scientific bodies.

He was married in New Haven, October 6, 1875, to Miss Susan Forbes, eldest daughter of Prof. Benjamin Silliman, Jr. She died February 17, 1890. Two daughters and one son survive him.

CHARLES S. HASTINGS.

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1875. Spectroscopic examination of gases from meteoric iron. *Ibid.*, vol. ix, pp. 294-302.
 Preliminary note on an examination of gases from the meteorite of Feb. 12, 1875. *Ibid.*, pp. 459-460.
 Examination of gases from the meteorite of Feb. 12, 1875. *Ibid.*, vol. x, pp. 44-49.
 Images produced by lightning. *Ibid.*, pp. 317-318.
1876. On the gases contained in meteorites. *Ibid.*, vol. xi, pp. 253-262.
 On the gases contained in meteorites. 2d paper. *Ibid.*, vol. xii, pp. 165-176.
1877. On the production of transparent metallic films by the electrical discharge in exhausted tubes. *Ibid.*, vol. xiii, pp. 49-55.
 On a new process for the electrical deposition of metals, and for constructing metal-covered glass specula. *Ibid.*, vol. xiv, pp. 169-178.
1880. Report on the polarization of the Corona during the total solar eclipse of July 29, 1878. From *Washington Observations*, for 1876, Appendix III; Reports on the Total Solar Eclipses of July 29, 1878, and Jan. 11, 1880, pp. 261-281. Washington, 4°.
1881. On the gaseous substances contained in the smoky quartz of Branchville, Conn. *This Journal*, vol. xxi, pp. 209-216.
 The polarization of light from comet *b*, 1881. *Ibid.*, vol. xxii, pp. 142-144.
 Polariscopic observations of comet *c*, 1881. *Ibid.*, pp. 372-374.
 An apparatus for the distillation of mercury in vacuo. *Ibid.*, pp. 479-484.
1888. Report on quartz plates used in determinations of sugar in U. S. Custom Houses, as chairman of committee of the National Academy of Sciences. *Rep't Nat. Acad. Sci.*, pp. 39-45.
1890. The Zodiacal light. *Forum*, vol. x, pp. 226-236.
1896. Cathode rays and their effects. *This Journal* (4), vol. i, pp. 235-244.
1898. The relation between structural and magneto-optic rotation (with D. A. Kreider). *Ibid.*, vol. vi, pp. 416-427.
1901. Spectrum of alternating current discharge studied with reference to its spectrum and especially the ultra-violet spectrum (with E. S. Downs). *Ibid.*, vol. xii, pp. 66-73.

SCIENTIFIC INTELLIGENCE.

I. CHEMISTRY AND PHYSICS.

1. *The Recovery of Gallium from Spelter in the United States.*—W. F. HILLEBRAND and J. A. SCHERRER state that they have received from a zinc works at Bartelsville, Oklahoma, more than 50 g. of metallic gallium containing a little indium, zinc, and calcium.* The metal or alloy is a liquid resembling mercury, which adheres tenaciously to glass or porcelain surfaces, but it does not do this when covered with hydrochloric or sulphuric acid. The interesting occurrence was observed by Mr. F. G. McCutcheon, chemist of the Zinc Company. He noticed peculiar beads or drops, of the appearance of mercury, which exuded from zinc-lead dross plates after they had been exposed to the weather for some time. This dross was the residue from a continuous re-distillation of commercial zinc at a temperature of about 1000°C . and amounted to about 60 lbs for 12,000 lbs of the zinc employed. The original zinc had been distilled from the ore at a maximum temperature of 1350°C ., so that it appears that a rather moderate difference in temperatures of distillation served to concentrate the rare metal. It is not certain from which of a variety of ores employed the gallium was derived, but it is thought probable that it comes from some Joplin ore. It appears that the gallium varies greatly in the residues obtained at Bartelsville, so that although there is a supply of about 45 tons of the material on hand, the yield as yet is very uncertain. The continued production of this residue is also uncertain, since the re-distillation of the zinc has been due to the present abnormal demand for high-grade spelter. It will be of interest to find if this metal, hitherto such a rarity, possesses any valuable qualities either by itself or as an alloy. The authors say that as far as is known to them the only uses for gallium that have been so far suggested are the use of an alloy with aluminium as cathode material in metal vapor lamps and for the production of optical mirrors. The fact that it "wets" quartz would seem to make it unfit for use in quartz thermometers for temperatures too high for glass and mercury instruments.—*Jour. Indust. and Eng. Chem.*, viii, 225.

H. L. W.

2. *A Proposed Method for the Profitable Utilization of Waste Sulphite Liquor.*—The manufacture of paper pulp by the sulphite process is a very large industry which produces an enormous quantity of a liquid containing sulphites and much organic matter. This liquor goes to waste at present and is a serious source of pollution to our streams. HERMAN V. TARTAR has described some experiments carried out in Oregon upon a process devised by Professor Charles Marchand for the purpose of utilizing this material. The method consists in treating with sulphuric acid,

*See further the article by Browning and Uhler, pp. 351-354 of this number.

distilling off the sulphur dioxide and saving it, and after several operations of concentration, oxidation, neutralization, etc., obtaining alcohol by fermentation and distillation. The important feature of this process appears to be the oxidation of the last traces of sulphurous acid by means of potassium permanganate, as this allows ordinary brewers' yeast to be used. The results of several experiments, usually on a scale of about 500 gallons, indicated promising yields of alcohol. The process removes the poisonous properties from the sulphite liquor, and it diminishes largely the amount of organic matter.—*Jour. Indust. and Eng. Chem.*, viii, 226.

H. L. W.

3. *Organic Chemistry*; by VICTOR VON RICHTER. Volume I, Chemistry of the Aliphatic Series. Translated by PERCY E. SPIELMANN. 8vo, pp. 719. Philadelphia, 1916 (P. Blakiston's Son & Co.).—Three American editions of this important work, translated by Professor Edgar F. Smith, have previously appeared, the last of which was published in 1899. On account of the rapid advances that have been made in the chemistry of the carbon compounds a new edition was desirable and is to be heartily welcomed, for this is one of the most valuable reference books for students of organic chemistry. The work of translation has now been taken from America to England, and it appears to have been carried out in a most satisfactory manner, following the eleventh German edition. While the statement is made that the translation has been carried out "After Prof. Edgar F. Smith's third American edition," it is evident that very thorough work has been done in the way of a new translation with suitable revision. The size of the book exceeds that of the previous American edition by nearly 100 pages, while the size of the pages has also been considerably enlarged. The appearance of this edition is of much importance to students of organic chemistry who read English more readily than German, and it is to be hoped that the second volume which treats of the aromatic series will soon appear.

H. L. W.

4. *Catalysis and its Industrial Applications*; by E. JOBLING. 12mo, pp. 120. Philadelphia, 1916 (P. Blakiston's Son & Co.).—This little book, which is of English origin, is one of a series of "Text-books of chemical research and engineering," edited by W. P. Dreaper. It gives very interesting accounts of the main principles and theories in regard to catalysis, and especially of its practical applications, which are numerous and of the greatest industrial importance. Sulphuric acid manufacture, industrial chlorine, salt cake, sulphur recovery, fixation of nitrogen, surface action and surface combustion, hydrogenation of oils, etc., dehydrogenation and oxidation, dehydration, and hydrolysis are among the topics discussed. The book is semi-popular in style, and it should appeal to a wide circle of readers.

H. L. W.

5. *An Introduction to the Physics and Chemistry of Colloids*; by EMIL HATSCHEK. 12mo, pp. 107. Philadelphia, 1916 (P. Blakiston's Son & Co.).—This is another of the "Text-books of

chemical research and engineering" originating in England. It gives a concise and very satisfactory account of the main features of this important branch of physical chemistry. Since many of the investigations discussed are recent, the book will be very useful to advanced students and teachers of chemistry who wish to gain a clear idea of the subject in its modern aspects. Moreover, the book should be of interest to many who possess only a moderate knowledge of physics and chemistry, since the behavior of colloidal solutions, the "sols," "gels," emulsions, etc., is a fascinating subject.

H. L. W.

6. *Historical Introduction to Mathematical Literature*; by G. A. MILLER. Pp. xiii, 302. New York, 1916 (The Macmillan Co.).—The following quotations from the preface are given in order to indicate fairly and concisely the author's point of view with regard to the text. "One of the difficult problems which present themselves to those interested in the diffusion of mathematical knowledge is how to establish a proper correspondence between the subject matter and the individual. This problem is especially serious in view of the fact that misfits along this line are often disastrous. Hence it is very desirable that the mathematical student be led to points from which he can overlook domains of considerable extent in order that he may be able to form a somewhat independent judgment as regards the regions which he might like to examine more closely. The main object of the present work is to guide the reader to such points of observation." "In plan and scope the present volume may perhaps claim originality."

The first two chapters are of a general character and deal with the history of mathematics at different periods and with the various types of mathematical literature, such as periodicals, encyclopedias, tables, and collected works. Definitions, divisions of mathematics, concepts, notation, terminology, errors, etc., are discussed in the third chapter. The next three chapters are devoted respectively to the fundamental developments in arithmetic, geometry, and algebra. The remaining chapter (VII) contains accounts of the lives and investigations of twenty-five prominent, deceased mathematicians. The volume closes with useful lists of important works of reference, such as bibliographies, encyclopedias, histories, etc. The material is presented in such a manner as to excite ever increasing interest as new realms are unfolded before the reader, and this fact, combined with the accuracy of the text, should make the book a valuable contribution to the field of mathematical pedagogy.

H. S. U.

7. *The Universe and the Atom*; by MARION ERWIN. Pp. iv, 314, with 58 figures. New York, 1916 (D. Van Nostrand Co.).—"The object of the present work is to furnish an explanation of the physical Universe and the Atom on simple mechanical principles." The constitution of the ether, the creation and structure of atoms, gravitation, and positive and negative electricity are all explained by simple kinetical considerations. It is shown that

stellar space is infinite in extent and that the normal luminiferous ether consists of standard particles which are situated at the vertices of equilateral triangles. The length of a side of the standard equilateral triangle is found to be 145.07×10^{-8} cm. (page 197), which we remark is about 145 times as great as the wave-length of Röntgen rays. This number is obtained by comparing equation

(14), namely, $\lambda = 8\pi \left(\frac{R_1^2}{R_1^2 - 2V_1^2} \right)$ with Balmer's series formula

$\lambda = 3646.13 \left(\frac{R^2}{R^2 - 4} \right) \times 10^{-8}$. Concerning the first relation

the author says: "For the purpose of identification for future reference, we will designate equation (14) as Erwin's Formula, expressive of the wave lengths of the radiations sent off by standard ether particles revolving around a centre for any assigned value of the radius of revolution of the particle of the First Order." Positive electricity appears to have no mass because it is composed of minute force rays. "In such a ray the traveling particle is very much smaller than the electron, since it is a particle of the wave sent off by the electron itself" (p. 227). Again: "The electric current is essentially a light wave, except that its traveling wheel is of greater amplitude than the traveling wheel of visible light wave" (p. 235).

The preceding remarkable conclusions and quotations are given to show that it is not possible to take a neutral position with regard to the text. It is either epoch-making or nonsense. In the opinion of the writer of this notice it is the expression of a very exaggerated case of confusion of ideas arising from miscellaneous reading of scientific writings coupled with complete ignorance of the laws of electrodynamics. In any event the book can only do harm to the reader who is not specially trained in scientific matters and in recognizing logical fallacies, since it contains many vague, loose and incorrect statements. The following quotations will suffice to verify the truth of this adverse criticism. "The tendency of the ball to fly off radially, away from the centre, or centrifugal force, is just balanced by the pull on the string toward the centre" (p. 26). "When light given out by glowing gases or vapors is examined in the spectroscope, the spectrum produced is found not to be continuous, but to consist of a number of bright lines in various parts of the spectrum. Fraunhofer . . . first studied these lines, and they bear his name" (p. 99). "The fact that the wave-lengths of the spectrum lines, for all the elements so far known, conform to Balmer's law, with only a change of constants in the formula, is a proof that . . ." (p. 103). "The writer suggests as probably the principal cause for the invisibility of the rays coming from the most distant stars, that they have been converted from visible rays into force rays, on the principle of composition" (p. 109). "Pressure is force, Weight is force, Momentum is force. The measure of a force F is the magnitude of the velocity acceleration f it will impart to a

given mass M in a given unit of time" (p. 150). "... and experiment has shown that the velocity acquired at the end of one second of time is 32.1912 feet or more accurately 980.965 centimetres" (p. 152). In the single italicised sentence on page 268 the names of certain chemical elements are spelled as follows: "phaseodymium, gadolinum, eubium, and lutecium." H. S. U.

II. GEOLOGY AND MINERALOGY.

1. *Thirty-sixth Annual Report of the Director of the United States Geological Survey to the Secretary of the Interior for the Fiscal Year ended June 30, 1915*; by GEORGE OTIS SMITH, Director, 1915.—This report is interesting in showing the progress which has taken place in the scope and operations of the Geological Survey during recent years. From being originally an almost purely scientific bureau concerned with the field work of topographic and geologic mapping and the publication of the results in form accessible only to experts, it has developed and organized successive divisions such as the Water Resources Branch and Land Classification Board. The latter embraces under the head of "hydrographic classification" such subdivisions as water power, irrigation, enlarged homesteads, and public water reserves. It is seen that the expanding sphere of the Survey results in a wider usefulness, especially to the people at large. The Director of the Survey recognizes the large educational function which the bureau may fulfill to the non-geological but intelligent public. This is shown by his paper given during the year entitled "Plain writing," by a larger amount of official correspondence with the general public, by an increased use of non-technical writing in the various reports, by simple explanations given on the backs of topographic sheets, and especially by the very interesting and instructive series of guide books issued during the year.

The magnitude of operations for the year is indicated by the summary given under the "division of accounts." The total appropriation for the fiscal year ended June 30, 1915, was \$1,405,520.00, but of this only \$110,000.00 was appropriated for geologic maps of the United States. J. B.

2. *Publications of the United States Geological Survey*, GEORGE OTIS SMITH, Director.—Recent publications of the U. S. Geological Survey are noted in the following list (continued from pp. 519-521, November, 1915):

Thirty-sixth Annual Report of the Director for the year ended June 30, 1915. Pp. 186; 2 pls. See notice above.

TOPOGRAPHIC ATLAS.—Forty-four sheets.

FOLIOS.—No. 195. Belleville-Breese Folio, Illinois; by J. A. UDDEN and E. W. SHAW. Pp. 13, with 5 pp. sections and maps.

No. 196. Philipsburg Folio, Montana; by F. C. CALKINS and W. H. EMMONS. Pp. 25, with 5 pp. sections and maps.

No. 197. Columbus Folio, Ohio; by G. D. HUBBARD, C. R. STAUFFER, J. A. BOWNOCKER, C. S. PROSSER and E. R. CUMINGS. Pp. 15; with 5 pp. maps, illustrations, etc.

No. 198. Castle Rock Folio, Colorado; by G. B. RICHARDSON. Pp. 13, with 6 pp. sections, maps, illustrations, etc.

MONOGRAPH, Volume LIV.—The Mesozoic and Cenozoic Echinodermata of the United States; by WILLIAM B. CLARK and MAYVILLE W. TWITCHELL. Pp. 341; 108 pls. See p. 221, February, 1916.

PROFESSIONAL PAPER, No. 95. Shorter Contributions to General Geology, 1915. Advance chapters.

MINERAL RESOURCES for 1915.—Numerous advance chapters on the metals, petroleum, coal, etc.

BULLETINS.—Nos. 565, 568, 573. Results of Spirit Leveling. R. B. MARSHALL, Chief Geographer. No. 565. Colorado, 1896 to 1914, inclusive. Pp. 192; 1 pl. No. 568. Missouri, 1896 to 1914, inclusive. Pp. 219; 1 pl. No. 573. Arizona, 1896 to 1915, inclusive. Pp. 123; 1 pl.

No. 595. Fauna of the so-called Boone Chert near Batesville, Arkansas; by GEORGE H. GIRTY. Pp. 45; 2 pls.

No. 598. Faunas of the Boone Limestone at St. Joe, Arkansas; by GEORGE H. GIRTY. Pp. 50; 3 pls.

No. 603. Geology and Oil Resources of the west border of the San Joaquin Valley north of Coalinga, California; by ROBERT ANDERSON and R. W. PACK. Pp. 220; 14 pls., 5 figs.

No. 604. The Phosphate Deposits of Florida; by GEORGE C. MATSON. Pp. 101; 17 pls., 2 figs. See p. 300, March, 1916.

No. 605. The Ellamar District, Alaska; by S. R. CAPPS and B. L. JOHNSON. Pp. 125; 10 pls., 10 figs.

No. 606. Origin of the Zinc and Lead Deposits of the Joplin Region, Missouri, Kansas, and Oklahoma; by C. E. SIEBENTHAL. Pp. 283, 11 pls., 16 figs. See p. 375.

No. 607. The Willow Creek District, Alaska; by S. R. CAPPS. Pp. 86; 15 pls., 5 figs.

No. 608. The Broad Pass Region, Alaska; by FRED. H. MOFFITT. With sections on Quaternary deposits, igneous rocks, and glaciation; by JOSEPH E. POGUE. Pp. 80; 8 pls., 3 figs.

No. 609. The fractional precipitation of some ore-forming compounds at moderate temperatures; by ROGER C. WELLS. Pp. 46; 2 figs.

No. 615. Rhode Island Coal; by GEORGE H. ASHLEY. Pp. 62; 5 pls., 3 figs.

No. 616. The Data of Geochemistry, third edition; by FRANK W. CLARKE. Pp. 821. See p. 376.

No. 617. Bibliography of North American Geology for 1914, with subject index; by JOHN M. NICKLES. Pp. 167.

Nos. 620, 621. Contributions to Economic Geology, 1915. No. 620, Part I. No. 621, Part II. Advance chapters.

No. 622. Mineral Resources of Alaska. Report on progress of investigations in 1914; by ALFRED H. BROOKS and others. Pp. 380; 11 pls., 8 figs.

WATER SUPPLY PAPERS.—Nos. 351, 352, 355. Surface Water Supply of the United States, 1913. N. C. GROVER, Chief Hydraulic Engineer. No. 351. Part I. North Atlantic Coast Basins. Pp. 189; 2 pls. No. 352. Part II. South Atlantic and Eastern Gulf of Mexico Basins. Pp. 84; 3 pls. No. 355. Part V. Hudson Bay Basins and Upper Mississippi River. Pp. 181, 2 pls.

No. 370. Surface Water Supply of Oregon, 1878–1910; by F. F. HENSHAW and H. J. DEAN. Pp. 829; 1 pl.

No. 371. Equipment for current-meter gaging stations; by G. J. LYON. Pp. 60; 37 pls., 10 figs.

No. 373. Water Resources of Hawaii; by G. K. LARRISON. Pp. 190.

No. 376–379. Profile Surveys prepared under the direction of R. B. MARSHALL, Chief Geographer. No. 376. Chelan and Methow River Basins, Washington. Pp. 8; 5 pls. No. 377. Spokane River Basin, Washington, and John Day River Basin, Oregon. Pp. 7; 10 pls. No. 378. Middle Fork of Willamette River and White River, Oregon. Pp. 8; 6 pls. No. 379. Umpqua River Basin, Oregon. Pp. 7; 13 pls.

No. 388. Surface Water Supply of the United States, 1914. Part VIII. Western Gulf of Mexico Basins. Pp. 124; 2 pls.

3. *West Virginia Geological Survey*, I. C. WHITE, State Geologist. *Wyoming and McDowell Counties*; by RAY V. HENNEN; aided by ROBERT M. GAWTHROP. Pp. xxvii, 783; 31 pls., 28 figs., 2 maps under separate cover. Wheeling, W. Va., 1915.—This is another of the valuable detailed county reports of the West Virginia Survey. It covers one of the principal areas of the great Pocahontas or "Smokeless" coal fields of West Virginia, giving a complete account of each coal bed, with analyses, estimates of unmined tonnage, and topographic and structural maps showing the elevation, dip and strike of the principal coal beds, including the famous No. 3 Pocahontas, covering the counties of Wyoming and McDowell, the latter leading every other county of West Virginia in the production of coal of the highest grade. (Price with maps, delivery free, \$2.50, extra copies of geologic map, \$1.00 each, and of topographic map, 50 cents.)

Lewis and Gilman Counties; by DAVID B. REGER, Assistant Geologist. Pp. xx, 660; 2 maps, 30 pls., 12 figs. March 1, 1916.—These counties lie within the coal, oil and gas belt of the State, and the economic geology and structural map of both are hence of great value and interest. (Price with maps, \$2.00; extra copies of geologic map, \$1.00 each, of the topographic map, 50 cents.) The soil map and report will be published later.

4. *Geology and Underground Waters of the Northern Llano Estacado*; by CHARLES L. BAKER. Pp. 225; 20 pls., 1 fig., 3 maps in pocket. Bulletin 57 of the University of Texas; Bureau of Economic Geology and Technology, J. A. UDDEN, Director. Austin, Texas, 1915 (Published by the University).—An earlier

bulletin of the University of Texas on the Mineral Resources of the State was mentioned in the February number (p. 224). The present volume discusses a region of great extent and for a half-century important for its stock raising. Attempts to reclaim it for agriculture have not been successful, in consequence of deficient water supply, and hence the importance for this region and others similar of investigations such as those here presented. The maps accompanying the report give for many localities the depths of the water-level, in part from actual measurements by the author, and in other cases as given by the owners or drillers of the well. This makes it possible to predict, for extensive areas, the depth of the water within some ten feet. The supply of surface water, however, is limited and hence the problem of conservation is essential.

5. *The Geography of the Fox-Winnebago Valley*; by RAY HUGHES WHITBECK, Pp. 109; 28 pls., 25 figs. Bulletin 42 of the Wisconsin Geological and Natural History Survey, E. A. BIRGE, Director, W. O. HOTCHKISS, State Geologist. Madison, 1915.—The bulletins of the Wisconsin Survey are many of them of a practical and educational character, treating of the industrial geography of the state with details as to selected regions. Bulletin 26, issued in 1913, was an introductory number given to the geography and the industries of the State as a whole; the present volume is the first of the regional bulletins. It discusses the valley of the Lower Fox River and Lake Winnebago, including its navigation, its cities and their industries, and also the agriculture. An earlier bulletin was devoted to the peat industries of the State (see p. 225, Feb. 1916).

6. *Geology and Mineral Resources of Jefferson County, Kentucky*; by CHARLES BUTTS. Kentucky Geol. Surv., 1915. Pp. 270, 65 pls., 3 text figs.—This work, the result of coöperation between the Kentucky Geological Survey and the United States Geological Survey, is one of the best county reports issued by any state of the American Union. Louisville has long been famous for the great variety of fine Paleozoic fossils which have been collected by at least three generations of enthusiastic workers out of its undeformed strata. The stratigraphy of the Falls of the Ohio region has therefore often been described, and now Mr. Butts, after going over most of the ground anew, presents all that is valuable, brought up to date and set forth in great detail with excellent illustrations. The exposed strata begin with the Richmond (Arnheim) of the Ordovician and continue with several interruptions into the higher Mississippian (Spargen). All the breaks are described and their significance pointed out. Faunal lists are given for each formation and many of the guide fossils are illustrated, making the book of general value for the greater part of the Mississippi valley. The report closes with a statement of the mineral and water resources of the county.

C. S.

7. *The Fauna of the Morrow Group of Arkansas and Oklahoma*; by KIRTLLEY F. MATHER. Bull. Sci. Lab., Denison Univ., vol. XVIII, 1915, pp. 59-284, 16 pls., 5 text figs.—This paper describes the stratigraphy and fauna of what appears to be the oldest horizon in the Pennsylvanian (lowest Pottsville) of America. The study is based on areas in northwestern Arkansas and northeastern Oklahoma. The Morrow formation consists essentially of shale from 200 to 420 feet thick, with three widely separated zones of limestones to which the various faunules described are restricted. The entire fauna consists of 158 species, of which 79 are new and 22 are not identifiable; at least 39 are well-known Coal Measures forms. From the Mississippian 12 species are derived, representing, among others, the significant genera *Pentremites*, *Archimedes*, and *Glyptopora*. Of new genera there are *Stereobrachierinus* and *Dietyocladia*. c. s.

8. *Mississippi, its Geology, Geography, Soils and Mineral Resources*; by E. N. LOWE. Mississippi State Geol. Surv., Bull. No. 12, 1915, pp. 335, 28 figs., 1 map.—This report is educational in scope and treats of the physiography, historical geology, underground waters, mineral resources, and soils of the state of Mississippi. There is also a geological map of the state. c. s.

9. *The Fauna of the Upper Devonian in Montana. Part 2: The Stratigraphy and the Brachiopoda*; by W. P. HAYNES. Ann. Carnegie Mus., vol. X, 1916, pp. 13-54, pls. 4-8, 1 map.—In this good piece of stratigraphic work the author brings together all that is known of the Upper Devonian in the region about Three Forks, Montana, and to this adds his own observations. The fauna consists of 94 species (9 new), and of these 86 are clearly of Devonian time. Only two forms (*Rhipidomella vanuxemi*, *Productella* cf. *arctirostrata*) pass into higher beds which are still beneath the Madison and even then contain "many lower Mississippian forms." The author regards zones 1 and 2 as "transitional," though he leaves them in the Upper Devonian. This conclusion is all the more remarkable since these beds have such characteristic Mississippian species as *Syringothyris carteri*, *Cleiothyridina sublamellosa*?, *Camartoechia metallica*, *Schuchertella crenistria*, and *S. inflata*. The evidence, as the reviewer sees it, is not that this faunule is transitional but that it clearly belongs in the Mississippian, as certainly as does the Louisiana limestone. c. s.

10. *Origin of the Zinc and Lead Deposits of the Joplin Region*; by C. E. SIEBENTHAL. U. S. G. S., Bull. 606, 1915; pp. 275; 11 pls, 16 figs.—This bulletin gives in a brief form a summary of the author's conclusions concerning the origin of the important ore deposits of the Joplin region. It is based upon a study of the district which has extended over a large number of years. The detailed evidence upon which these conclusions are based will be presented in a later volume.

The Joplin district is on the western edge of what is known as the Ozark uplift, the center of which is formed by the St. Francis

mountains, which are composed of Pre-Cambrian rocks. Sloping from this center are sedimentary strata made up largely of Ordovician limestones, which were capped by a shale. The limestones, lying between two impervious formations, formed an artesian basin. It is believed that the metal content of the ore bodies originally existed in a disseminated state throughout the limestones and was gradually dissolved by the underground waters and transported by them to the open ground which lay at the base of the overlying shale formation and there deposited again in the ore bodies.

W. E. F.

11. *Meteorites: Their structure, composition and terrestrial relations*; by OLIVER CUMMINGS FARRINGTON. Pp. x, 233; 65 figs. and frontispiece. Chicago, Ill., 1915 (Published by the author).—The subject of meteorites has been one which has excited great interest, both on the popular and scientific side, ever since the nature and origin of the "falling stones" was first determined. This is explained by the general uncertainty as to their source, the rarity of their fall and the unexpected and often spectacular phenomena attending it; further, the specimens of every fall have their own peculiarities, while they give the only opportunity available for the actual contact-study of materials of extra-terrestrial origin. The author is particularly fitted for the preparation of a general volume on this unique subject, since he has contributed much himself to our general knowledge of meteorites, both as to a description of new occurrences and from a more comprehensive standpoint. An exhaustive study of the North American meteorites by him was noticed in a recent number of this Journal (February, 1916, p. 223). It is also interesting to remark that the Field Museum at Chicago contains the largest collection of meteorites in the world. This collection, which is under the care of Dr. Farrington, was inaugurated in 1894, and in 1912 the private collection of Henry A. Ward, which alone included upwards of six hundred falls, was added to it. Although a volume of only 220 pages, the present work covers well, and concisely, the entire subject, from the discussion of the phenomena of fall and geographical distribution, to that of the structure and composition of meteorites, their classification and origin, as well as their relation to terrestrial rocks. This volume will at once interest the intelligent amateur and be of value also to the trained specialist.

12. *The Data of Geochemistry*; by FRANK WIGGLESWORTH CLARKE. Third edition. Pp. 821. Washington, 1916. Bulletin 616 of the U. S. Geological Survey.—All interested in the relations existing between chemistry and the problems of the earth's substance, history, and structure are much indebted to Professor Clarke for his work on *Geochemistry*, which has now reached a third edition. It appeared first in 1908 (U. S. G. S., Bulletin 330) and again as a second edition in 1911 (Bulletin 491). The many workers who have used the volume do not need to have its general scope explained (see this Journal, vol. xxv, p. 458); it is

interesting, however, to note that the present issue includes upwards of a hundred pages more than the first edition of 1908; this shows the care and thoroughness with which the author has brought the subject up to date.

13. *Guida al Corso di Mineralogia: Mineralogia Generale*, Second edition; by GIOVANNI D'ARCHIARDI. Pp. 543; 576 text-figures. Pisa, 1915 (Enrico Spoerri).—The first edition of this valuable work, by the distinguished mineralogist of Pisa, Professor Antonio d'Archiaridi, appeared in 1899 (see vol. ix, p. 160). It is pleasant to note that this second edition is by the son of the original author and his successor at the University of Pisa. The work has been rearranged and much enlarged, and will doubtless have a still wider circle of usefulness than its predecessor.

14. *School of Mines and Metallurgy, University of Missouri. Bulletin, vol. VIII, No. 1, January, 1916. List of References on concentrating ores by flotation*; compiled by JESSE CUNNINGHAM, Librarian. Pp. 106; 2 pls. Rolla, Mo., 1916.—This bibliography is based upon the library of the School of Mines and has been prepared primarily for the use of its students engaged in experiments in the flotation laboratory. It is expected, however, that it will serve as a guide to the general study of the subject. Some 900 titles are included, and a special section (pp. 44–51) is devoted to the subject of colloids and surface tension as related to the important theory of oil flotation processes. The publications of the Institution since its beginning in 1902 make an impressive total of 299 volumes with 79,500 pages.

III. MISCELLANEOUS SCIENTIFIC INTELLIGENCE.

1. *Carnegie Institution of Washington*; ROBERT S. WOODWARD, President. *Year Book No. 14, 1915*. Pp. 429; 3 pls., 4 figs. Washington, 1916.—The decade which has passed since Dr. Woodward became president of the Carnegie Institution has been an important period in the development of its policy and in the experience which has been gained in regard to the most effective methods of promoting scientific research. This subject is taken up in detail, and the presentation is not only of great interest to the general public, but of especial value to other institutions having more or less similar ends. The aggregate amount allotted for the work of the Institution during the past year was upwards of \$1,250,000, but even with this large income it is still subjected to very definite limitations and any considerable increase in its scope is not to be looked for. On the contrary, the considerable diminution in the purchasing power of money during the past twenty years has made it essential to curtail research in order to live within income; it is, hence, much to be desired that the endowment fund may be increased.

Of the total amount allotted for the year as already stated, a sum of upwards of \$700,000 was devoted to the larger depart-

ments to which, for a considerable number of years, the Institution has given its chief support; about \$145,000 was devoted to the minor grants; \$73,000 to publications; \$57,000 to administration; also \$250,000 to the reserve fund. The minor grants cover the different departments of science with also history, literature, etc., and the names of more than 40 individuals working for them are noted. The publications of the year include 23 volumes with 4,686 octavo pages and 1,466 quarto pages. More than 45 additional volumes are now in progress.

The reports of the president and executive committee (pp. 1-52) are followed by the usual detailed statements from the directors and others having charge of the special departments of investigation (pp. 55-342). Of these, the following may be mentioned: Dr. MacDougal tells of the varied botanical work done at the Desert Laboratory at Tucson; Dr. Davenport of the experimental evolution work at Cold Spring Harbor; Dr. A. L. Day of the work on igneous rocks, on calcium carbonate and on secondary enrichment of ore bodies at the Geophysical Laboratory; Dr. A. G. Mayer on the researches on marine biology at Tortugas, Fla., Dr. G. F. Hale on the results attained at the Mount Wilson Solar Observatory; Dr. L. A. Bauer of the extended magnetic survey of the ocean by the "Carnegie," and other researches. The investigations, coming under the "minor grants," are described by the gentlemen concerned (pp. 343-411).

The titles of recent publications of the Carnegie Institution are given on p. 305 of the March number; the following are to be added:

No. 86. Ptolemy's Catalogue of Stars: A revision of the *Almagest*; by CHRISTIAN H. F. PETERS and E. B. KNOBEL. Pp. 207; 4 pls., 4 figs.

No. 232. Psychological Effects of Alcohol. An experimental investigation of the effects of moderate doses of ethyl alcohol on a related group of neuro-muscular processes in man; by RAYMOND DODGE and FRANCIS G. BENEDICT. Pp. 281; 32 figs.

No. 233. The Physiology of the new-born Infant: Character and amount of the Katabolism; by FRANCIS G. BENEDICT and FRITZ B. TALBOT. Pp. 126; 10 figs.

2. *Report on the progress and condition of the United States National Museum for the year ending June 30, 1915*; by RICHARD RATHBUN, Assistant Secretary in charge. Pp. 215. Washington, 1916.—The National Museum has moved rapidly forward since its new and handsome building was completed some five years since. The total amount appropriated for the museum's maintenance the past year was \$421,000, and the number of visitors to the new building was nearly 322,000, showing the extent to which the collections appeal to the general public. There were nearly 1500 accessions to the collections, aggregating about 300,000 specimens; of these more than one-third were in paleontology, while 70,000 marine invertebrates and 51,000 plants were also added. These and other accessions are described in detail. The

National Gallery of Art, which is an important part of the Museum, also received numerous additions, conspicuously those presented by Mr. Charles L. Freer of Detroit, supplementary to his other large and valuable collections given in 1906.

3. *Library of Congress. Report of the Librarian*, HERBERT PUTNAM, and *Report of the Superintendent of the Library Buildings and Grounds*, FRANK L. AVERILL, for the fiscal year ending June 30, 1915. Pp. 221; 6 plates.—An important part of the work of the Library of Congress during the past year has been the development of the plans having to do with the "preparation of such indexes, digests and compilations of law as are required for Congress and other official use." An appropriation of \$25,000 by Congress for this end became available on July 1, 1914, and the Librarian indicates here the many special lines on which the work planned will be carried out. The Library of Congress now contains 2,364,000 books, with large numbers of manuscripts, prints, maps, pamphlets, etc. The increase over the preceding year of 110,564 books is considerably less than the average, in consequence of the war conditions existing in Europe. An important gift is that of Mrs. Ridgely Hunt of a collection of 316 volumes, chiefly Italian works from the library of Wm. Cruger Pell; other gifts are also enumerated. Of the purchases, the most notable is that of 10,741 volumes of Chinese literature selected by Dr. Hing Kwai Fung. The East Asiatic collection in the Library is now in excess of 45,000 volumes.

4. *The John Crerar Library*; CLEMENT W. ANDREWS, Librarian. *A List of Books on the History of Industry and Industrial Arts*. January, 1915. Prepared by AKSEL G. S. JOSEPHSON. Pp. 456. Chicago, 1915.—The present volume is the eleventh of the bibliographical publications of the John Crerar Library and follows a related volume, issued in 1911, which gave a "List of Books on the History of Science." Although based upon the resources of one Library only, this is an important contribution to bibliography in general, as it is the first attempt to bring together a large number of titles in the subjects mentioned; it is important to note that these fall in a department in which the Library is particularly strong. This list includes the economic history of the industries, including the history of commerce and banking, while the history of the science of economics is included in the earlier volume mentioned on the History of Science. Titles are arranged largely on the basis of the class catalogue with numerous references to countries and centuries so as to aid the student to find the material desired.

5. *Modes of Research in Genetics*; by RAYMOND PEARL. Pp. vii, 182. New York, 1915 (The Macmillan Company).—Some of the most important recent experiments in the breeding of animals have failed to yield their potential scientific value because of the lack of sufficient precision in the methods employed. The investigator does not always realize the importance of the principles of biometry and of a clear conception of the meaning of statistical data for the success of his work. In this book the author discusses the inadequacies of current modes of

biological research and shows the practical application of biometry to many diverse problems. The nature of statistical knowledge and the mathematical analysis of inbreeding are fully and lucidly explained, with a final chapter discussing the relation of the science of genetics to the practical art of breeding. Although most of the subject matter has appeared elsewhere, its incorporation in book form will be of great service both to the geneticist and the intellectual practical breeder.

W. R. C.

6. *Scientific and Applied Pharmacognosy*: Intended for the use of students in pharmacy, as a hand book for pharmacists, and as a reference book for food and drug analysts and pharmacologists; by HENRY KRAEMER. Pp. viii, 857, with 313 text figures. Philadelphia, 1915 (published by the author).—As the author remarks in his preface, the science of pharmacognosy is one of the most important branches of applied botany. This is not only because the vast majority of drugs are of vegetable origin, but also because the methods employed in studying them are largely those of the plant histologist. Problems connected with the conditions under which medicinal plants reach their best development fall also within the domain of the science, and the pharmacologist must frequently make use of micro-chemical reactions in studying the constitution of his drugs. In the present volume the varied needs of the student of pharmacognosy are supplied in a noteworthy degree. In a short introduction the scope of the science and the nature of its special problem are outlined, and this is followed by a presentation of the principles, definitions and rules employed in pharmacognosy. The greater part of the work, nearly 800 pages, is taken up by the detailed description of the numerous vegetable drugs, arranged according to the Engler-Prantl system. Under each of the more important drugs full information is given about the plant from which the drug is derived, about the appearance of the drug as an article of commerce, and about its histological structure, both intact and in a powdered condition. The active principles of the drug are then discussed from a chemical standpoint, and attention is called to the nature of its adulterants and to the methods by which they may be detected. At the close of the volume the very few drugs of animal origin are considered, and a helpful artificial key for the study of powdered drugs is given. The illustrations are profuse and of a high degree of excellence. Many of them are original and most of the others are taken from standard European works. In the majority of cases the figures bring out histological details, but some of them show morphological features or microscopic crystals. The work will surely prove indispensable to pharmacists, and should be of much service to botanists in other fields.

A. W. E.

7. *Methods in Plant Histology*. Third Revised Edition; by CHARLES J. CHAMBERLAIN. Pp. xi, 314; with 107 text-figures. Chicago, 1915 (The University of Chicago Press. Price, \$2.25, net).—Professor Chamberlain's *Methods of Plant Histology* has established a place for itself in botanical laboratories. In the third edition, as in the previous editions, the work is divided into

two parts, the first general in character and the second more specialized. In the first part, among the subjects treated, the following may be particularly mentioned: stains and staining, the glycerine method, the Venetian turpentine method, and the paraffin method. In the second part the various groups of plants and the methods especially adapted to their study are considered. When compared with the earlier editions the changes to be noted are largely in matters of detail, although an interesting chapter on photomicrographs and lantern slides has been added.

A. W. E.

8. *Laboratory Manual of Horticulture, with illustrations of methods, equipment, and apparatus*; by GEORGE W. HOOD. Pp. vi, 234; with 52 text-figures. (Ginn & Company, 1915. Price \$1.00.)—The present manual is an outgrowth of courses in horticulture given by the author at the Ohio State University and other institutions. It is thoroughly practical in character and gives directions for seventy-eight exercises to be carried on in the laboratory or in the garden. Following each exercise is a blank page for the student's notes. The greater part of the book is devoted to cultivated fruits, and the various methods of budding and grafting are clearly and fully described.

A. W. E.

9. *Bacteriological Methods in Food and Drugs Laboratories*; by ALBERT SCHNEIDER, University of California. Pp. 277; 93 illustrations. Philadelphia, 1915 (P. Blakiston's Son & Co.).—An admirable guide for analysts engaged in the sanitary examination of foods. It embodies standard methods of bacteriological investigation, as well as more recent and untried methods which promise to be of practical value in this field. Unification of bacteriological procedure appears to be the keynote. The first chapter of twenty-three pages with six full-page plates is devoted to micro-analytical and chemical methods of detecting certain food substances and food adulterants and impurities. The remainder of the book is devoted to bacteriological technique and closely related matters. Of particular interest is the part treating with the detection of bacteria and moulds in canned soup, catsups and other preserved foods.

L. F. R.

10. *Publications of the Astronomical and Astrophysical Society of America*. Volume II. Pp. 240, with numerous illustrations. Ann Arbor, Michigan, 1915.—This volume contains a summary of the five meetings of the Society, beginning with the eleventh meeting in 1910 and extending to the fifteenth meeting in 1913. The abstracts of the papers read in each case are given with considerable fullness. Of especial importance is the report of the Comet Committee of 1909–1913, having particular reference to the return of Halley's comet in August, 1908. The observations upon it at various points are given in detail and some twenty-eight plates present the results of the photographs of the comet at Diamond Head, Hawaii, by Ferdinand Ellerman, with notes upon the same by E. E. Barnard.

11. *Proceedings and Collections of the Wyoming Historical and Geological Society* for the year 1915; edited by Rev. HORACE EDWIN HAYDEN. Vol. XIV. Pp. 287. Wilkes-Barré,

Pa., 1915 (Coxe Publication Fund).—This publication of the Wyoming Society, in addition to details in regard to officers, committees, etc., contains five articles, of which two are particularly worthy of note. The first is by Professor J. F. Kemp on the "Buried River Channels of the Northeastern States." This subject as applied to the Hudson River valley has already been developed by the same author and is presented in articles published in this Journal (Oct. 1908, pp. 301-323; July, 1912, pp. 1-12). In the present paper, however, the scope has been widened so as to bring together the observed facts for a number of other valleys, as the Wyoming valley in Pennsylvania, the Walkill valley in New Jersey, the valleys of Seneca and Cayuga lakes in New York, and those of the Nashua, Merrimac and Charles rivers in Massachusetts. The submarine channels, which have been described by a number of different authors, are also included in the discussion and the conclusion drawn that these buried channels, of the Pliocene or closing Tertiary, indicate a land-elevation of 300 to 400 feet.

A second paper, covering nearly two hundred pages, gives the "Reminiscences of Hon. Charles Miner, 1780-1865." Mr. Miner, who has been called the "Pennsylvania pioneer," was the author of the well-known History of Wyoming, in 1845; the present paper was prepared by the late Dr. C. F. Richardson, whose widow is Mr. Miner's granddaughter. Although the subject of this memoir does not bring it within the scope of this Journal, it may be remarked that it presents a most interesting account of a region which has long been famous in the history of the country. A special edition of 300 copies of these memoirs has been printed and donated to the Society by Mrs. Richardson; its sale to libraries should do much to establish the proposed "Charles Miner Fund" for the general uses of the Society.

OBITUARY.

SIR CLYMENTS ROBERT MARKHAM died at his home in London on January 30 in his eighty-sixth year. He took part in the Franklin Search Expedition to the Arctic in 1850-51, and later made important contributions to geography both in the field and as one of the Secretaries, and afterward President, of the Royal Geographical Society.

SIR WILLIAM TURNER, vice-chancellor and principal of the University of Edinburgh, died on February 15 in his eighty-fourth year. He was distinguished as an anatomist besides his life-long services in the cause of the higher education.

DR. CHARLES WILLARD HAYES, chief geologist of the U. S. Geological Survey from 1902-1911, died at Washington on February 9 in his fifty-seventh year.

PROFESSOR IVAN PETROVITCH PAVLOV, the distinguished Russian physiologist, died at Petrograd early in February at the age of sixty-five years.

DR. P. CHAPPUIS, well known for his work in gas thermometry, died at Basle, February 15.

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FOURTH SERIES

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THE
AMERICAN JOURNAL OF SCIENCE

[FOURTH SERIES.]

ART. XXVIII.—*Effects in Mokuaweoweo of the Eruption of 1914*; by HARRY O. WOOD.

MOKUAWEOUEO is the summit crater of Mauna Loa, the great volcano on Hawaii. It is a large depression, produced by collapse, in the broad, summit plateau which terminates the grand dome of the mountain. It is not much visited.

Eruption began in this crater shortly after noon on November 25, 1914. It undoubtedly continued until January 11, 1915,—for rising fumes illumined at night could be seen from the Hawaiian Volcano Observatory, at Kilauea, as late as January 10. The Observatory is situated almost due east from the crater at a distance of about 22 miles (about 35 kilometers), and it is at an elevation about 9700 feet (2900 meters) nearer the level of the sea. No symptoms of eruption were observed later than January 11, 1915.

Under the auspices of the Hawaiian Volcano Observatory the writer has made three expeditions to Mokuaweoweo.

In 1913 he first visited it in company with Mr. J. W. Green of the U. S. C. & G. S., when nearly four complete days were spent there at an elevation slightly in excess of 13,000 feet (4000 meters). On that occasion camp was made at about 10 A. M. on Sept. 30, and broken early in the morning of October 4, 1913. It was located on the summit level at a point on the southeast margin of the crater close to the edge of the cliff. Its approximate site is shown on the maps accompanying.

On this expedition the writer spent one day in walking completely around the crater margin on the summit plateau,—a distance of 12 to 14 miles: another day in a hurried exploration of the eastern plateau region; and a third in traversing the southern and central part of the crater floor and a large

portion of the elevated platform south of it. (See the maps, figs. 1 and 13.) Photographs were made both by Mr. Green and by the writer.

Again on December 15, 1914, while the recent eruption was still in progress, the writer was one of a party to reach the crater margin, at the identical place where his previous stay was made, at about 1.15 P. M. This time a little less than an hour was available for observation of the eruptive action and of changes in conditions in the crater. Photographs were made by Prof. T. A. Jaggar, Jr., and by the writer.

In August, 1915, the third expedition was carried out. Camp was established again in the same spot, on August 18. The summit was reached at 10.30 A. M. Camp was broken in the early morning of August 28, making a stay of almost ten complete days on the summit plateau. A general reconnaissance was made of the crater—on its floor, more especially in the northern and central parts west of the axis—, and of the summit region on the northeast, east and south. A great many photographs were made.

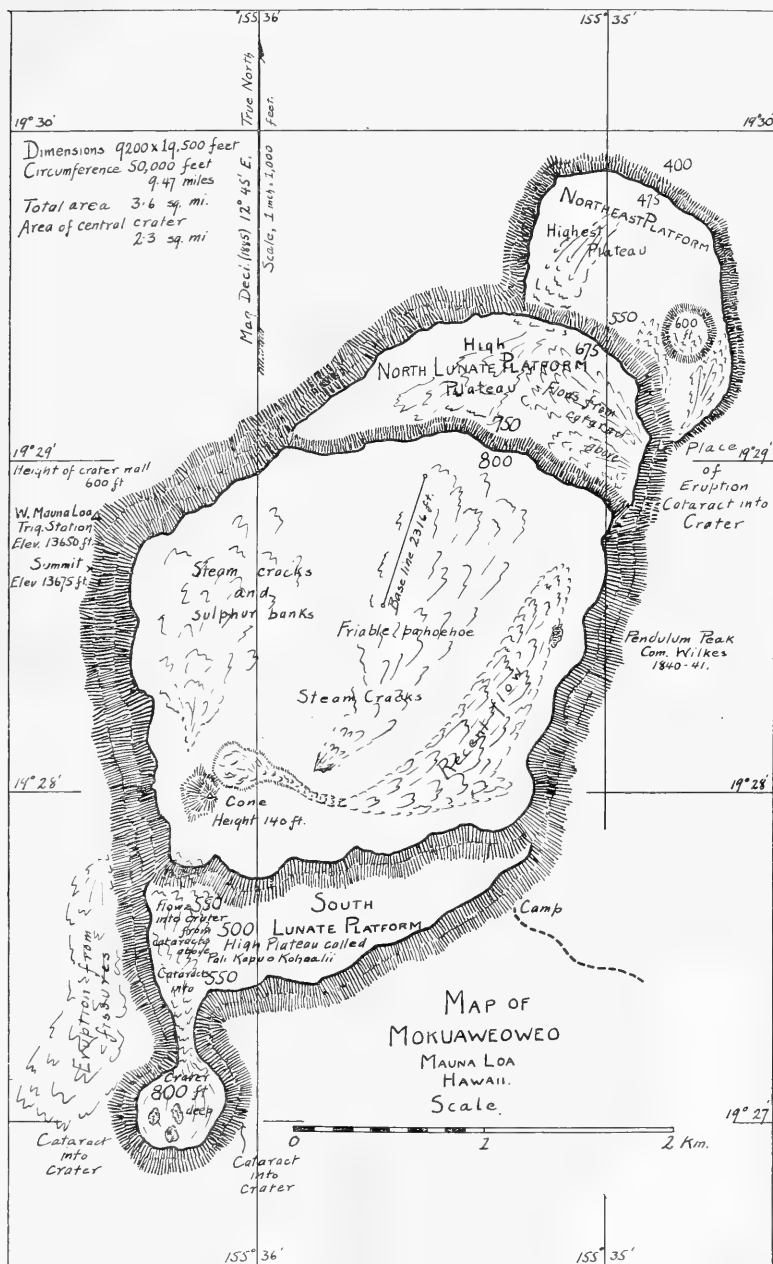
A thorough account of the results of these expeditions to the summit area must be left for a later time. This will require a somewhat extended study. But a statement of the effects produced by the 1914 eruption in Mokuaweoweo will be attempted here on account of the immediate interest these possess. To do this previous conditions must be described since no succinct account is extant.

No map of Mokuaweoweo has been made since that surveyed by J. M. Alexander in 1885. Nevertheless the outline of the crater and its walls have changed only slightly since then. Through further collapse a deep pit of small area has formed, making a shallow recess in the east wall of the crater near the north end of the central depression. Also, on the west wall there have occurred, probably, small, further, partial collapses; one close by the north end of the central depression, the other a little south of the north end of the crater as a whole. These changes barely affect the general *outline* of the crater. Its *floor*, however, has changed very markedly.

This map of 1885 necessarily forms the base for this work. It is here re-drawn (as fig. 1) since at present it is not available in a form well adapted for reproduction for printing.

Attention must be directed to conditions as mapped in 1885. There was then a large central depression terminated east and west by cliff walls rising directly to the summit plateau, but at the south and north limited by cliffs of less height rising to the surfaces of depressed, crescentic benches which have been known respectively as the "south lunate platform" and the "north lunate platform." Beyond the south lunate area the

FIG. 1.



summit walls approached closely and then opened out to engirdle the "south pit," which was known to Wilkes as "pohaku o hanalei." At the north the "north lunate" terminated against a low cliff rising to a platform at a still higher level situated at the northeast end of the crater as a whole. In this paper this will be referred to as the "northeast platform." In it was sunk a small, deep, "north pit" near its eastern border. According to the figures given by Dana* on the cut of this map published by him, in 1885 the floor of the large central depression was 800 feet (about 244 meters) below the highest, western, summit point, 250 feet (about 76 meters) below the south lunate platform near its west end and 50 feet (about 15.2 meters) below the north lunate bench near its center. This bench, moreover, stood some 125 feet (about 45.7 meters) lower than the edge of the northeast platform near its center.

Subsequent to 1885 there has been action in Mokuaweoweo on several occasions, as follows: *Possibly* in 1887 for a day or two beginning January 16, preceding the flow at the south,—though there was no *direct* observation or *definite* report of this; in 1892 for three days, more or less, beginning December 1; in 1896 for about fifteen days beginning April 21; in 1899 for four or five days beginning July 1, preceding the flow at the northeast; in 1903 for about two months beginning October 6; and *possibly* in 1907 for a short time beginning January 10, preceding the flow at the south.

Then followed the action beginning on November 25, 1914, and ending on or about January 10, 1915, the effects of which are here under discussion.

As a result of all this action at the summit prior to 1913 the writer found that the crater in October of that year exhibited marked changes with reference to the map of 1885.

The floor of the large central depression had been built up very considerably by outflow of lava upon it. Thus the height of the cliff under the south lunate platform had been much reduced, though no numerical estimate of the amount can be ventured. Also, in all probability, a small portion of this platform, near its contact with the west wall, had collapsed into the central depression, making a recess at this place deeper than that mapped in 1885.

At the north side of the central depression the floor had been up-built so much that new lava had over-run by far the greater part of the north lunate platform—its lower central portion,—leaving uncovered only its higher, sloping portions, which rise at the west and east to their contacts with the main

* J. D. Dana, *Characteristics of Volcanoes*, plate X, p. 181. New York, 1891.

walls. These remaining parts were bounded against the central depression by low cliffs which soon wedged out from the crater margin toward the center. But enough remained in these end portions to indicate the location and former course of the cliff of the north lunate platform.

Here the up-building of the floor of the main crater amounted to a value much in excess of 50 feet (about 15.2 meters), at the very least, over a considerable part if not all of the floor at the north. For, in 1913, it no longer was anything like so much as 125 feet (about 45.7 meters) from the new surface on the site of the north lunate platform up to the edge of the northeast platform. While no definite figure can be given, the difference was largely due to upbuilding, for it was true everywhere along the course of the cliff. But in part it may have been due to minor fault-block movements,—for at some time which we must presume later than the survey since there is no hint of it on the available map (though there is indication of it on a revision made in 1896 but not based on survey), a short gap had been formed in the cliff of the northeast platform near its west end, and through this the general level of this platform was seen now to be lower than the cliff walls delimiting it on the side of the former north lunate platform. Nevertheless, the northeast platform in 1913 still stood conspicuously higher than the level of the new floor immediately south of it; see fig. 4a.

In 1913 in the southern part, where it was closely visited, the floor of the central depression was formed of very coarse block lava but in a general sense it seemed level. Any tendency of this rough lava to conform to the general surface of a flat cone, as is the case with the floor of Kilauea, was so slight as to escape notice.

Two cinder cones were then seen on the floor. Both were "double cones,"—that is, each was made up of two semi-cones formed separately, but simultaneously, by the falling of cinders on either side of an elongated orifice situated on a fissure system which passed between the two halves.

The larger of these cones was in the central part of the main depression a little to the west of its N.E.—S.W. axis. The gash which divided its parts was irregular and ragged. It had a general N.E.—S.W. course. At the northeast this led out into a small depression, 10 to 15 feet (3 to 5 meters) deep, in which were seen several fusion-sculptured dome-forms rising from its floor. At the S.W. end of this cone this gash swerved around toward the southeast and continued as a depressed channel,—quite clearly the course of flowing lava,—probably formed in the closing stages of the eruption (1903) which produced the cone. This gash-channel led for some distance

FIG. 2a.

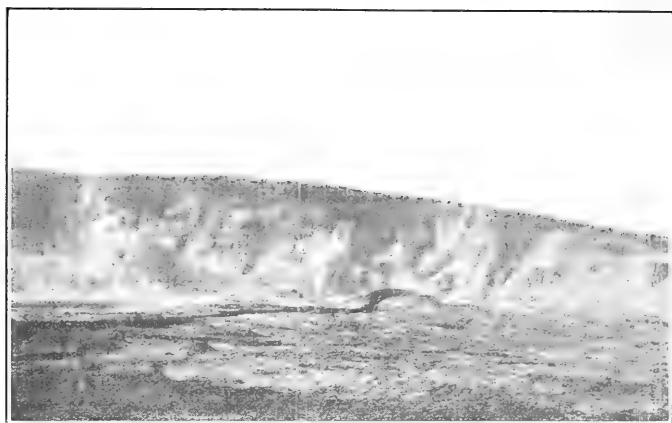


FIG. 2b.

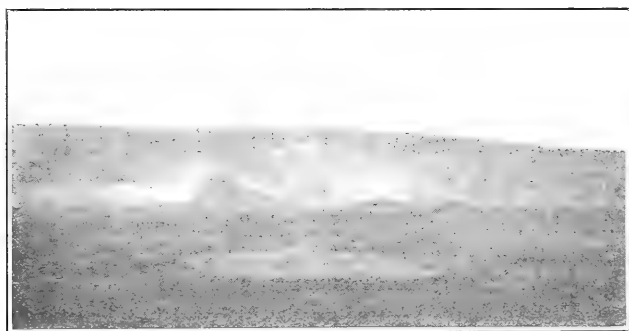
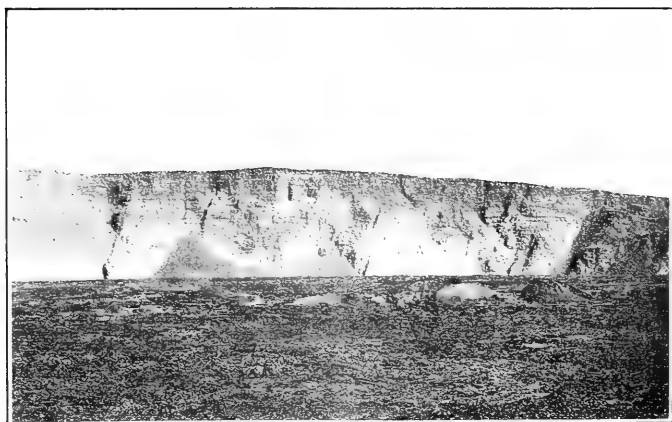


FIG. 2c.



through a tract of intimately mingled, shattered pahoehoe and an a-a of a very coarse, rough, and hard sort. The floor and walls of the channel were chiefly of smooth pahoehoe, affording for a short distance a good pathway from the cone. Elsewhere all about the cone there was either a-a or badly shattered pahoehoe. See the photograph fig. 2*a*.

The smaller cone seen in 1913 was not closely visited. It was situated in the southwest part of the main depression not far from the point of a miniature promontory jutting out from the west wall. Thus it was near to, but not within, the mouth of the recess in the south lunate platform where this adjoins the west wall. A little to the north of the cone, against the wall, was an area of smooth pahoehoe. Save for this, this cone was surrounded by a-a tracts and patches of rough-looking pahoehoe. See the photograph, fig. 5*a*.

In general in 1913 the floor of the main depression was a highly complicated pattern of intermingled pahoehoe and a-a. In the absence of a suitable map, and especially in view of the short duration of this expedition, no mapping of such details could be undertaken. It happens, however, that on the floor near the eastern end of the south lunate platform there was a small area in which a-a and smooth pahoehoe were arranged in a well-marked pattern which lent itself well to photographic record,—and here is possible a comparison of details with the conditions seen in the field and photographed in the latest expedition in 1915. See the photographs, figs. 4*a* and 4*c*. It is only here and in the neighborhood of the larger cone that *detailed* comparisons are possible. Fortunately the action in 1914–15 was such as to produce easily recognizable changes without the necessity of referring to miniature details of the floor.

The three photographs, 2*a*, 3*a* and 4*a*, were made in 1913 from the edge of the crater wall directly in front of camp, just above the south lunate platform a little to the south of its east end. Fig. 2*a* looks a little W. of N.W.; 3*a*, a little north of N. of N.N.W.; and fig. 4*a*, a little E. of N. These three pictures practically cover, in panorama, the view from camp-site of the floor region and walls north from the central part of the crater.

Attention is directed to the cone in fig. 2*a*; the gash through it; the small depression just north of it, barely visible in the photograph; the channel leading southeastwardly from the gash; the slightly depressed area of pahoehoe in the middle ground; and to the details of the west wall in the background, especially near its junction with the floor. Particularly, notice should be taken of the fact that the cone is silhouetted against the wall, and that outcropping layers of rock are to be seen at the base of the wall-talus to the west of the cone.

Turn now to fig. 2*c*, a photograph from the same view-point made in August, 1915, but with a lens of slightly different focal length. (F, 22^{cm}.) In this in front of the cone of 1903 is to be seen a line of cones, with one of considerable size, extended along a N.E.—S.W. course. The older cone is no longer *silhouetted* against the west wall, for there the floor has been built up so as to cover the outcropping rock-layers earlier seen at the base of the talus and to bury other features also, thereby raising the junction of wall and floor so much that the line of sight from camp to this junction now passes above the summit of the older cone. Without detailed citation,—careful comparison of fig. 2*c* with fig. 2*a* will show the obliteration of numerous features seen on the lower west wall in 1913,—thus pointing incontrovertibly to a *considerable upbuilding*, in the neighborhood of 75 feet (23 meters), of the floor surface at the west throughout the range covered by the view. The gash in the older cone is still visible, but the small depression north of it is almost hidden behind the newer cones. The channel leading to the southeastward and the depressed area of pahoe-hoe are no longer seen.

Let us now compare these views with fig. 2*b*. This photograph was taken from the same view-point with a lens of shorter focus on December 15, 1914, twenty-one days after the beginning of eruption. Unfortunately this view is not very clear. However, it can be seen that on that date the line of new cones had already formed, thus obliterating the channel and hiding from vision the depression north of the older cone. The depressed area of pahoe-hoe, though slightly changed in outline, was still conspicuous. The older cone (and to some extent the newer ones) was still silhouetted against the west wall, and despite the haziness of the photograph it is sure that the junction of the west wall and floor was still much lower than in August, 1915.

The region immediately surrounding the older cone was visited at close quarters both in 1913 and in 1915. The cone itself has undergone no change.

In its immediate vicinity there is no new lava, except fresh cinders from the rift-cones nearby. The small depression at the north remains unchanged. See telephotograph view, fig. 7.

In connection with the latest eruption a fracture was produced at least 3000 feet (900 meters) long, perhaps as much as 4800 feet (1450 meters), along a general N.E.—S.W. course. This passed east of and nearly tangent to the older cone. Along this the line of new cones arose, built around orifices out of which sprang fountains of molten foam. For the most part this fracture is an insignificant thing, merely a linear sys-

tem of minor cracks, almost unnoticeable. It certainly cannot be dignified by the appellation of fissure. Yet it was formed suddenly at the initiation of the summit eruption; it is remarkably rectilinear; it is within and in the course of the great rift

FIG. 3a.

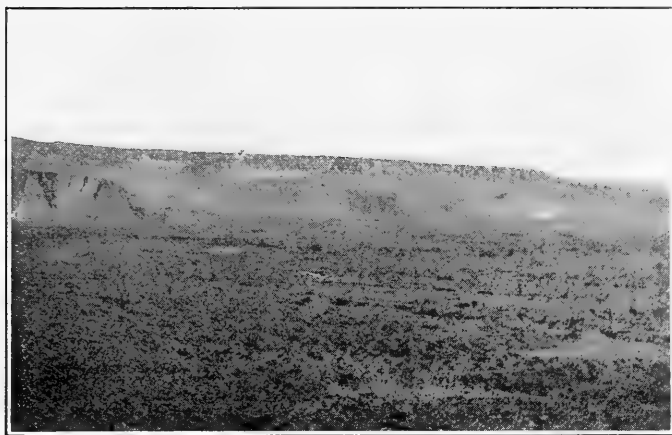


FIG. 3b.



through the mountain; and a group of weak earthquakes attended its formation.

However, where it cuts across the former course of the channel which led from the older cone there the *older lava* is

uplifted bodily 10 to 12 feet (3 to 4 meters) along a very narrow tract lying on both sides of the fracture. And between this uplifted and fractured tract and the older cone a very short segment of the channel remains undisturbed. See the photograph, fig. 11.

In briefest terms,—fig. 3*a* shows that, in 1913, in the regions of the crater just north of that previously considered, the black lava cascade emerging on the west wall fell into contact, at the bottom, with the still unsubmerged surface of the west remnant of the north lunate platform. In 1915, as fig. 3*b* shows, this part of this remnant had been buried by overflow. But a pho-

FIG. 4*a*.

tograph made on December 15, 1914, though too hazy to be reproduced, shows that this overflowing had not taken place on that date.

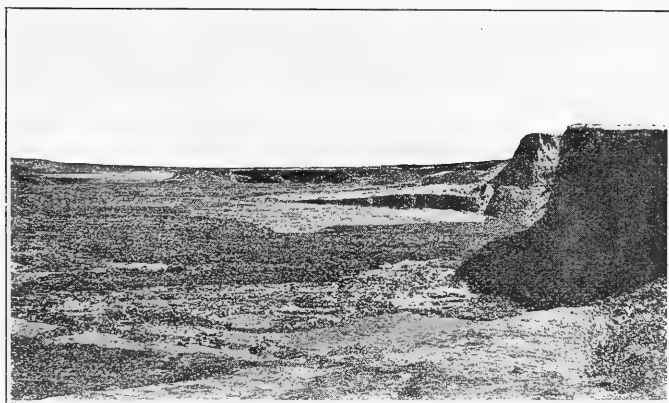
Fig. 4*a*, which depicts the northern and central part of the crater floor, shows that in 1913, there was still a considerable cliff separating the northeast platform, at the gap, from the lava floor below. No estimate of its height is attempted. In 1915, as shown in fig. 4*c*, the floor at this place had been built up so that only a suggestion of the cliff remains,—a low bank 9 to 10 feet (about 3 meters) high, to show that these surfaces are still at different levels. As we should now expect, fig. 4*b*, a photograph taken on December 15, 1914, shows that this upbuilding at the north had not then taken place. Even a little snow rested on the floor not far from the base of this low cliff,—a strong indication that no new lava had yet reached this region of the floor.

A careful study of the details of the *main floor* in the middle ground, in figs. 4*a* and 4*c*, develops the fact that near the junction of the east wall and the south lunate platform there remains without change a considerable tract characterized by

FIG. 4*b*.



FIG. 4*c*.



a recognizable pattern due to intermingling of a-a, piled crusts of pahoehoe and smooth, unbroken pahoehoe. Only on the extreme west of these views has this pattern been interfered with. However, farther north in the same views, it is seen that in 1915 new rough lava had flowed quite to the east wall,

where in 1913 there was a smooth pahoehoe surface. Reference to fig. 4*b* shows that this had flowed, in part at least, before December 15, 1914.

Turn now to the figs. 5*c* and 5*b*, 5*b*₂, photographs taken from

FIG. 5*a*.



FIG. 5*b*₁.



FIG. 5*b*₂.



the same view-point in front of camp in August, 1915, and on December 15, 1914, respectively. These views look about W.N.W. to a part of the crater not successfully photographed from this station in 1913. However, this region was then photographed with success from a point on the west wall look-

ing about S.S.E., fig. 5*a*. In the interim great changes have taken place in this part of the central depression. This is the southwest and south central part of it, north from the cliff wall of the south lunate platform. In 1913 this was an area of commingled pahoehoe and a-a with a small "double" cinder cone and an area of smooth pahoehoe adjoining the west wall north of this. Everywhere the cliff wall of the south lunate

FIG. 5*c*.

platform was well marked and fairly high. Examine the foreground and middle ground, fig. 5*a*.

As early as December 15, 1914, considerable changes had been effected here. Eruption was then in progress. There was a lava lake of moderate area—say 500 feet (about 150 meters) long,—confined by a wall of spatter outfall so that it stood from 10 to 20 feet (from 3 to 6 meters) above the level of the surrounding floor. Out of this, lava appeared to be flowing in an overcrusted stream through a gap in the spatter wall at the south. Near the northwest margin of this lake a fountain of molten froth was playing to estimated heights of 150 to 200 feet (45 to 60 meters). The cinders and pumiceous matter outfalling from this were building a three-quarter cone, fig. 5*b*₂. From this place of upwelling, presumably, much lava had already poured out onto the adjacent crater floor and streamed away in several directions, at one place reaching the east wall. In the south-central part it had already built up to the level of the south lunate platform, and it had nearly obliterated the cliff wall here. This lava lake and cone were near to if not exactly over the site of the smaller cone of 1903.

The following account* of the action during the night of November 27-28, 1914, with the accompanying sketch map (fig. 6), is germane to the matter under consideration :

An ascent was made by two good observers, Messrs. Leslie Forrest and L. C. Palmer, from Pahala on the evening of November 27, and they spent the night on the edge of Mokuaweoweo southeast near the Wilkes station. I am indebted to these gentlemen for the following description and the accompanying plan. They reached the rim in the early evening, watched the fountains off and on all night, and returned down the mountain next morning. The activity was confined to the main central basin of Mokuaweoweo, where an elongate area of new lava overspread the middle part of the floor in a northeast-southwest direction and seemed to overlap the northern lunate platform of the Alexander map. Mr. Palmer did not see the remnant of that platform at all. This new lava was an elongate fountaining pool at the south, and apparently overflows on the floor at the west and north.

There were eight main fountains, mostly playing continuously, the southernmost a tremendous sheet fountain, estimated 150 feet wide, apparently playing above a north-south crack which determined its elongate character. As seen from the east it varied in width (length) like a flickering flame on a ragged, flat lamp wick, but played continuously to heights estimated between 300 and 400 feet. The height was estimated by comparison with the west wall behind it.

The other fountains were lower, forty to fifty feet high, the southern ones having in part the character of shore jets working in grottoes. Several mounds had been built up by spatter, and some of the fountains were concealed behind these mounds, or possibly within them.

At F2 (see diagram) was a spasmodic fountain which erupted at varying intervals, sometimes ten minutes, sometimes an hour or more, resembling a fiery flower pot, and shooting up to heights estimated at 200 feet.

The new lava flows glowed from time to time, especially between two and four a. m. November 28, when there was general recrudescence. There was white vapor on the south lunate platform and all around the northern end of the lava field. In the greater fountains the lava jets reached the curved upper limits of their trajectories, still red and blackened in their downward course.

The following is the text of Mr. Palmer's description of the sketch-map :

"If the southern platform is 550 feet down (Alexander), the lake of lava must have been about 600 feet below the top of the mountain. Circles are fountains (F). 'M' are mounds with fountains back of them or else cones with fire coming through them. (Mr. Palmer identified no definite flames.) I could not tell at night, and by morning there did not seem to be any lava coming over them at all.

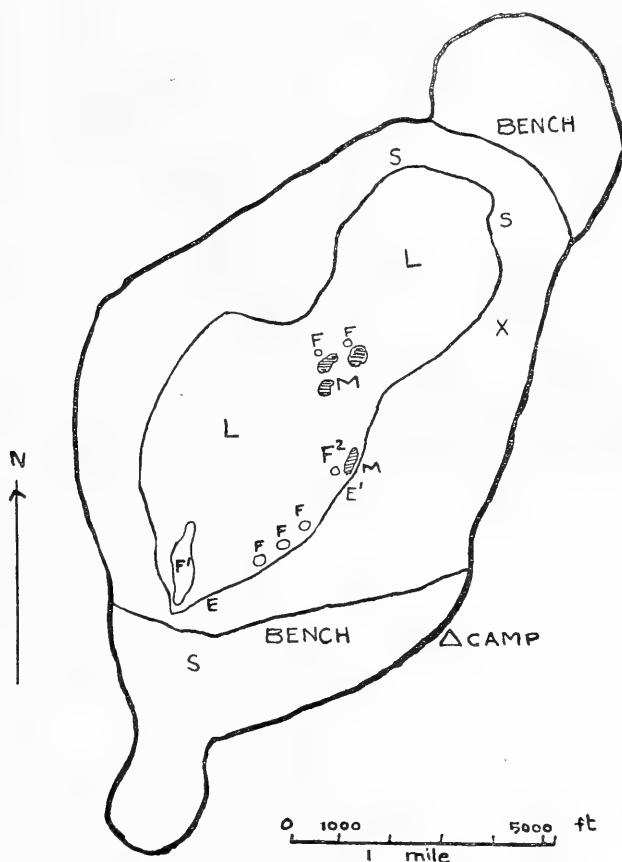
"F1 is a large fountain, varying in width, as it sometimes included a small fountain to the south ; about 150 feet was the average width, but that is only a guess. The great fountain played continuously about half the height of the west wall of the crater, sometimes higher, particularly between two and four a. m., when it must have reached a height two-thirds or three-quarters that of the west cliff.

"F2 is a fountain which sent up a single column of lava at irregular intervals, not as high as F1. 'S' is steam or vapor. Most of the night there was black crust over most of the lava area, but towards morning, between two and four, it disappeared, particularly in the northern part, where the surface was all red for a while, but by daylight it looked black again. Between the lake and the east wall (x) the lava was the same level as the lake, but black, except that a little fire showed through at X."

* Weekly Bulletin of the Hawaiian Volcano Observatory, ii, 31, pp. 166-167, Honolulu, December 1914. T. A. Jaggar, Jr.

While this map (fig. 6) can lay no claim to accuracy, it will be seen that in the first two or three days of eruption considerable outflow of new lava had occurred.

FIG. 6.



Outline of Mokuaweoweo, November 27-28, 1914.
 Sketched by L. C. Palmer from the J. M. Alexander map of 1885.

- | | |
|----------------------------|------------------------|
| X—Glowed a little. | F—Fountains. |
| L—New Lava, mostly flows. | S—Steam (white vapor). |
| EE'—Edge of distinct pool. | M—Mounds. |
| F'—Large fountain. | F2—Irregular fountain. |

In fig. 5c, August, 1915, it is seen that further changes took place here after December 15, 1914. Careful comparison of details shown in the west wall in figs. 5b, 5b₂ and 5a brings out the fact that the floor region near this center of eruption

FIG. 7.

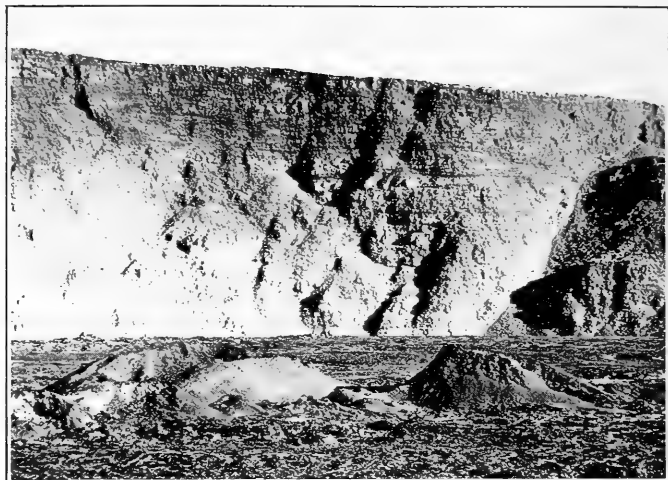
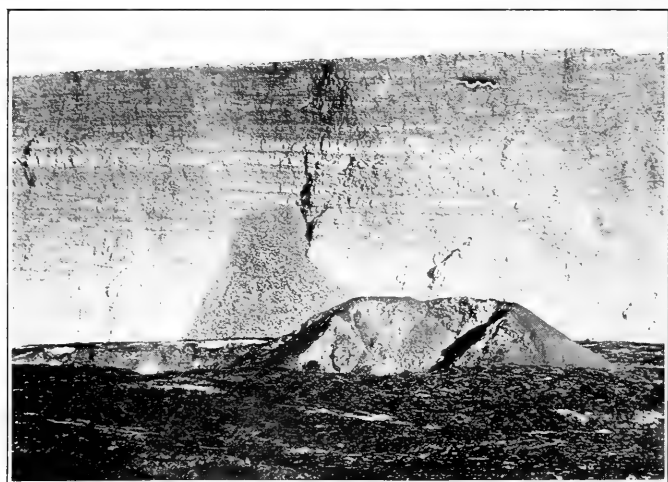


FIG. 8.



later was built to still higher elevations than when the fountain was seen playing. For features then observed were afterward obliterated or hidden from view from the station at camp. Also the cone eventually was built larger and higher; and the region of the lava lake of December was in August an irregular collapsed area, or pit. See the photograph, fig. 8.

The evidence of change between stages, cited already, throws light on a very interesting point. Though in some respects a digression, this matter at bottom is pertinent to the present subject.

During the course of the recent eruption it was noticed from the Hawaiian Volcano Observatory that *apparently* fumes were emitted at first in great volume; and at night the illumination was both brilliant and widespread; but that both the emission of fumes and the night illumination rapidly diminished, until on December 8 they had vanished. The glow appeared to diminish in brilliancy as well as in extent. Beginning again on December 13 with a glow barely visible from the Observatory, both the fumes and the illumination apparently increased until about the end of the month, and then again diminished rapidly until the apparent cessation of eruption on January 10, or 11, 1915.

At the time this behavior was puzzling, and its interpretation presented difficulties. In the first place, it was possible that the effect was due to changes in summit meteorological conditions, and so was in no way dependent upon changes in eruptivity. But if a real variation in fuming and illumination were the fact, this still could be understood in two ways—almost diametrically opposed.

It was a legitimate inference that it might be due to decreasing activity, the apparent increase in illumination in that case being due to a better reflecting fume-cloud. It is well known that when the lava surface falls low in Halemaumau, at Kilauea, great volumes of the gases then emerge from fumaroles at the sides and in the talus slopes as dense white fumes, instead of burning to transparent or translucent products over the molten surface. With this reaction in mind Jaggard wrote: “. . . an increase of fumes is to be looked for, by analogy with the habit of Kilauea, if the fountains in Mokuaweoweo are still diminishing.” *

In regard to this view it is proper to point out that the effect at Kilauea is due to subsidence of the magma level in the Halemaumau pit,—not to diminishing surface action alone; and that the diminishing of the fountains in Mokuaweoweo without such subsidence of the magma did not produce either

* Weekly Bulletin of the Hawaiian Volcano Observatory II, 32, p. 178, Honolulu, December 31, 1914. T. A. Jaggard, Jr.

real or apparent increase of fuming during the last days of November and the first days of December, 1914. Successive visits up to December 15 strongly indicated that both the fountain action and the fuming had diminished together.

It was also a legitimate inference, which at the time the writer was inclined to consider favorably, that the increase in fuming and in night illumination, if real, indicated an increase in eruptive action in the summit crater.

Consequently it is interesting to see that the study of the photographs made on December 15, 1914, with those made more recently, in August, 1915, definitely establish that after the December visit great quantities of lava were discharged from the neighborhood of the elevated pool then observed. Later than December 15, 1914, flows ran quite to the cliff edge of the northeast platform and both there and all along the west wall (and after this date to a less extent along the central part of the wall of the south lunate platform as well) these flows built up the floor in the western part of the main crater by many feet.

As all the evidence visible from the Observatory, whether fumes, or illumination, indicated a cessation of eruption on or before January 11, 1915, these findings lend strong support to the view that visible action at the surface underwent increase during the latter part of December, with genuine increase in the emission of fumes and genuine increase in the brilliancy of illumination.

Such behavior would accord with the increase in eruptivity in Kilauea during the same fortnight, and could be interpreted as a response to an increase in earth-strain, as indicated by an hypothesis of control by earth-strain variation which is being tested at Kilauea. An exposition of this hypothesis is nearly ready for the press.

Such action is also in accord with the usual circumstances of the sporadic activity in Mokuaweoweo. For during its long, dormant intervals only very small quantities of fumes escape there.

Specifically touching on this point, contrasting the activity in Mokuaweoweo in 1896 with that in Kilauea as he knew it, Dr. Benedict Friedlaender wrote :

" . . . the differences between the activity of Kilauea lake and that of Mokuaweoweo are to be enumerated. From the molten lava of Kilauea there arises only a thin smoke, that in the reflected light is intensely bluish, and if looked at against the bright sky, yellowish brown. A volcano cloud proper does not exist as a rule, and only under certain circumstances, mostly in the early morning and again at sunset. The invisible overheated steam will condense to a cloud, but I invariably noticed that the seeming volcano cloud was a free, floating mass of condensed

steam without any appreciable connection with the lava lake.* Mokuaweoweo, on the other hand, as long as it was active nearly *always had a cloud*; and that cloud *always* had a noticeable trunk or pillar of smoke; the latter, as I could see from the top, arose almost entirely from the fountains."†

In 1913 the writer approached the central region of the floor by way of the south lunate platform, which was reached by descent from the summit plateau at a point a little north of camp, over a rough talus slope which debouched onto the northeast end of the platform. In 1915 this way had become hazardous through the falling away of footholds near the top. Hence it became advisable to approach over the northeast platform so as to enter the main depression at its extreme northern part by descent over the low cliff, only about nine or ten feet (3 meters) in height, which now marks the margin of the platform.

At present the writer has no considerable knowledge of the details of changes which have or may have taken place on the surface of the northeast platform since 1885; but it is sure that none were produced here in the latest eruption.

Climbing down the low cliff by way of an a-a serac—the term is used advisedly—a surface of hard, blue-black pahoehoe was encountered; but this was interrupted by patches of a-a, and was traversed by long, irregular strips of a-a in a most complicated way. This rough lava, also, showed the same color and texture of surface. As we have seen, all this was found to be lava of 1914.

The contact of this new body was a badly fractured, irregularly subsided, miniature block-fault zone; and the parts of this immediately at the edge stood about five feet (1.6 meters) below the general level of the new surface. Unquestionably this fracturing and faulting took place after the new lava here had solidified to a depth of many feet; but it is not known whether flowing action had ceased altogether when this occurred.

The surface texture of this new lava is unlike any type seen in Kilauea. Some similar types of old date are seen about the margin of Mokuaweoweo, and the identical characteristics were seen in 1913 on surfaces in the south central part of the main crater.

The texture of the surface of both the pahoehoe and the a-a is *bladed*. Long, flat, blade-shaped spiculæ stand out from the general surface in such a way that their long axes make slight angles with it, chiefly in the direction of flow, and their short

* While the description of Kilauean conditions given here by Dr. Friedlaender does not cover the range of fuming action observed more recently—still the contrast he sought to emphasize does not appear to be invalidated.—Ed.

† B. Friedlaender, Mokuaweoweo in Activity, Hawaiian Annual, 1897.

axes also are slightly upturned so that cutting edges and spiked points characterize the resultant surface. While in a certain sense brittle, this new lava is hard and strong and these points and edges are more than usually sharp. Hence the cutting and rasping effect of this surface, on footwear for example, is more destructive than is commonly the case, even on a-a.

In different parts of the flow these blades vary from the size of a steel pen to that of a table-knife blade, or even larger over very small patches. They also exhibit differences of individual form and arrangement depending somewhat on the miniature physiographic development of the surface. For example, on the surface in channels of rapid flow they stand almost exactly parallel with the streaming and are long spiky blades, or even spikes, slightly inclined up from the surface as they point down-stream. On rounded, toe-lava projections they are broad, short, very flat blades showing a tendency to radiate in their axial arrangement from some central region of the rounded surface. On broad warped surfaces they have ordinary blade shapes with a slightly divergent arrangement of their axes. The photograph, fig. 9, illustrates the general character of this texture on an ordinary pahoehoe surface.

These blades sometimes form the surface of thin crusts separated from the thick, dense layers below by a coarsely vesiculated stratum from one to six inches thick. But again they make the surface of layers from one to three feet thick, or more, that are relatively dense throughout—in some places very dense indeed for an effusive basalt.

In nearly all places the surface of this new lava is blue-black to bluish steel-gray in color, but there are numerous patches where thin layers of surface oxides give it the color of gold, or streaked arrangements of color with iris hues.

North of the cone of 1903 and west of the rift of 1914, see the map (fig. 13), practically all of the floor of 1915 is of lava of this type, whether pahoehoe, or a-a, or an intermediate block-pahoehoe (a sort due to fragmentation with piling while still flowing). It was estimated that there is more pahoehoe than a-a on this part of the floor, and nearly as much block-pahoehoe as a-a.

This region of the crater floor shows at least one rude, crescentic, rifting zone which appears to mark approximately the position of the former cliff of the north lunate platform. No differences of general level were observed on opposite sides of this broken zone. Other less continuous, and in all ways less sharply defined zones of rifting were seen nearer the center of the crater.

Though a few typical "schollendomes," or low, elliptical domes riven along their crest, were seen, this region of the floor is remarkably free from them. But it is characterized

FIG. 9.



FIG. 10.



by numerous, roughly circular, down-faulted areas, only a few feet (say two to three meters) in depth, with overhanging margins. These range in size from ten feet (about 3 meters) to, say, about 300 feet (or about 100 meters) in diameter; the larger are less regular, but even these approximate to the circular outline.

≈ This whole field of new lava is much fissured but, except as noted, the fissures have a wholly irregular arrangement, and distribution.

¶ Through this field the cones were approached along a series of leads or irregular lanes, which involved very little going

FIG. 11.



except on pahoehoe. Only a few zigzag crossings over strips of a-a, or fissure zones, were necessary. The appearance of these cones viewed obliquely from a distance of a half-mile, or so, is seen in the photograph fig. 10. In this they are shadowed by a cloud in early afternoon, which thus affords a bold silhouette of them.

Just before these cones are reached from the north, we come to the edge of the new lava of 1914-15 and then pass across a small field of older pahoehoe (1903) characterized by a surface of miniature flow tubes. Some of this lava had a pumiceous surface. In a short distance this becomes covered by fallen clinkers and pumice, first from the cone of 1903, and later from the cones of 1914 also.

The surrounding of the 1903 cone have been described already. The photograph fig. 11 is a view looking about S.W. from the summit of a small cone (1914) just east of that of 1903.

This sights along the west side of the southern part of the 1914 rift. In the distance is the largest cone of 1914. In the right, middle ground is the *uplifted* and *fissured* pahoe-hoe of 1903 athwart the channel of that date. In the left middle ground is the second in size of the *minor* rift-cones of 1914. The man standing in front of it serves to fix a scale for it. The magnitude of the crater, in which this particular cone is an insignificant feature, can also be comprehended. The foreground shows 1903 pahoe-hoe nearly covered with cinders from the two eruptions.

FIG. 12.



The photograph fig. 12 is a view looking N.E. from a point at the N.W. foot of the largest of the rift-cones of 1914, distinctly showing three smaller ones in the continuation of the rift to the N.E. The floor in the foreground is made up of 1914 cinders.

Finally, very sparing fresh cinders and bits of filiform, basaltic pumice, as well as sparing Pele's hair, were found in a few places protected from wind drift on the summit surface south of camp.

It only remains to summarize the findings on the map, fig. 13, and the cross-section, fig. 14.

The Maps.

The scale of the Alexander map of 1885 is given, on blue-print copies, as 1000 feet to the inch; and the latitude and longitude of the trigonometric station on the west wall, north

of the summit point, are given out by the office of the Territorial Survey as

19° 28' 50.26" N. Lat.

155° 36' 27.66" W. Long. from Greenwich.

The elevation of this station was found by triangulation as 13,650 feet (about 4,160 meters) above sea.

Accepting these coördinates and this scale as accurate, the meridians and parallels drawn on the maps, figs. 1 and 13, have been plotted with care. However, they do not agree with values determined by Wilkes in 1841, nor with those determined by Green, in 1913, (working, only, to tenths of minutes of arc). And none of these agrees with the coördinates plotted on the cut of this map published by Brigham.* Presumably the Alexander values, stated to hundredths of seconds of arc, are accurate—at any rate more so than the others. But it is proper to bring to notice these discrepancies since they cast doubt in some degree on the accuracy of the cartographic net.

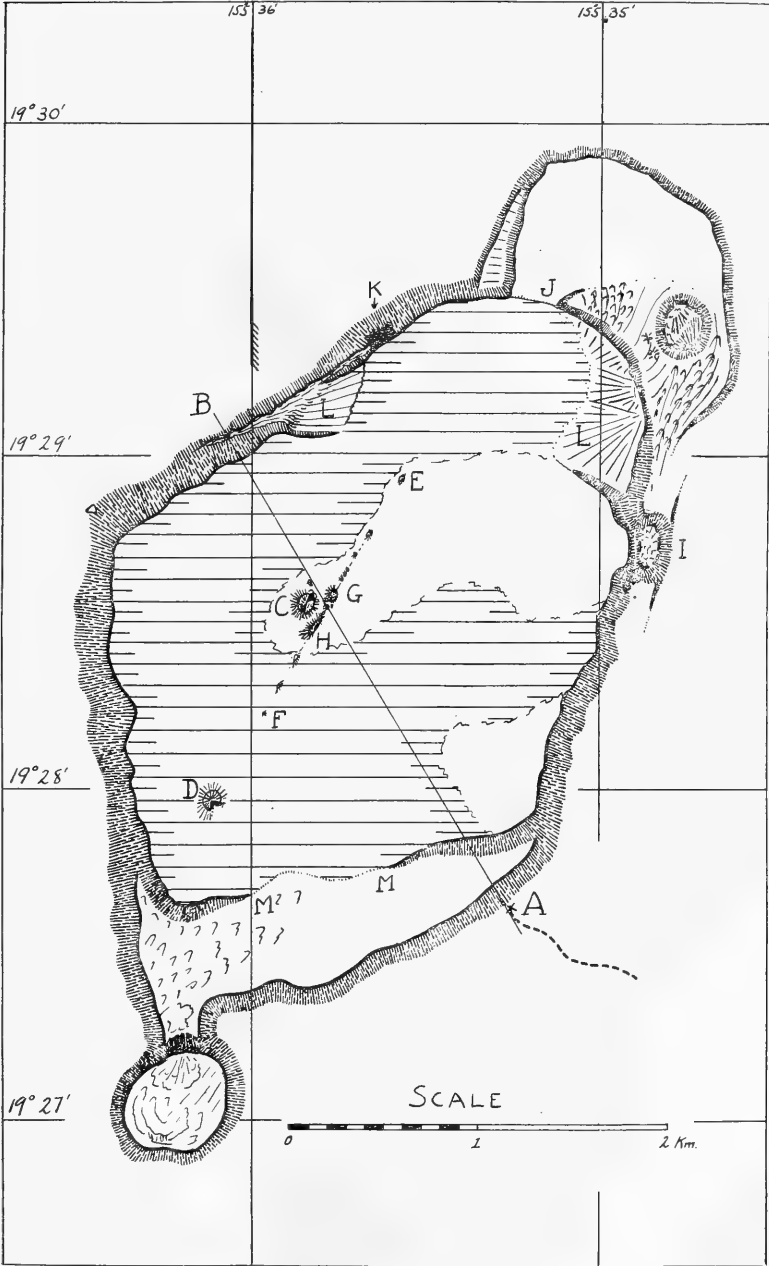
The 1885 map, fig. 1, is simply re-drawn, by tracing methods, from a blue-print copy. Some changes in lettering have been made and some new lettering added; and certain things shown on the copies published by Dana and Brigham, but not on the blue-print copy, are here added.

The revised map, fig. 13, makes no pretense to *strict* cartographic accuracy. But an attempt has been made to *express* upon it changes, which strike the attention of the observer, that have taken place in the outline, and upon the floor, down to August 1915. Unfortunately, this revision contains an error. The line of new rift-cones drawn on it was fixed by a compass triangulation, (a method obviously uncertain in an area of rapidly varying magnetic variation, as is the case here): after the map was completed it developed from the critical study and measurement of the photographs that this line, as drawn, is slightly out in azimuth. Its northern end, E, should be swung eastwardly about five degrees around its southern end, F, as a center.

No new surveying data, except with pocket compass, have been obtained. However, the revised map has been made with much care,—especially from the geologist's point of view,—and the study and measurement of many photographs is embodied in it, as well as the other results of the direct work in the field. Except for the error mentioned it is thought to be substantially accurate. This is true also of the cross section, fig. 14.

* W. T. Brigham, The Volcanoes of Kilauea and Mauna Loa, Mem. B. P. Bishop Museum, II, 4, p. 159, Honolulu.

FIG. 13.



ART. XXIX.—*The Composition of Natural Bornite*; by
E. T. ALLEN.

THE analyses presented in this brief paper were originally undertaken to determine the purity of material needed in an investigation of the copper-iron sulphides. They were further extended, however, when it was realized that the composition of bornite was not fully settled. The formula Cu_5FeS_4 , which is given in most of the text-books was deduced by Plattner from an analysis of material from Cornwall, a locality where bornite is intimately intergrown with chalcopyrite and notoriously impure.*

As early as 1875 Cleve† recognized that the above formula agreed with but few analyses; in fact it did not agree closely with any. Six analyses of bornite made under Cleve's direction pointed to the formula Cu_5FeS_4 and in line with these he found two others recorded in the literature. However, four other analyses done in Cleve's laboratory led to more complicated formulæ and Cleve concluded that there must be several similar minerals all of which had passed under the name of bornite. In 1903 Harrington,‡ in a critical consideration of this question, made analyses of six different bornites from widely separated American localities, and found that the results all agreed with the formula Cu_5FeS_4 . Harrington states that his specimens were "carefully selected," and his statement is corroborated by the uniformity of his results and his specific mention of impurities in some of the specimens he examined, especially specimens from Cornwall. But a lens, on which Harrington was dependent at that time (1903), is not an entirely safe instrument to decide the homogeneity of an opaque mineral. Intimate intergrowths with other sulphides are found to be very common when bornite is examined by the metallographic method.§

My own analyses have been confined to specimens of bornite which, after careful microscopical study on several polished surfaces, have been shown to be practically free from other sulphides.¶ Graton and Murdoch kindly furnished me with

* Plattner, Pogg. Ann., xlvii, 351, 1839; Varrentrap, *ibid.*, p. 372; B. J. Harrington, this Journal (4), xvi, 151, 1903; Joseph Murdoch, *Microscopical Determination of Opaque Minerals*, pp. 35 and 36.

† Geol. För. Förh., ii, 526, 1875.

‡ Loc. cit.

§ Graton and Murdoch, Trans. Am. Inst. Min. Eng., xlv, p. 45, 1914. Murdoch, loc. cit., pp. 35-6.

¶ This statement is not strictly true of the bornite from North Carolina, but as will be seen later, the way in which the chemical and microscopical analyses of this sample agree leaves no doubt that the material examined by the two methods was practically identical.

the purest bornites they had met with in their extended investigations of mineral sulphides at the Harvard Mining School, while several others obtained from different sources were carefully examined by Dr. H. E. Merwin of this laboratory.

The following table includes analyses of all the bornites of satisfactory purity which the author was able to get.

It will be observed that the analyses agree closely with the formula Cu_5FeS_4 with the exception of that of the bornite from North Carolina. The discrepancy in this case is satisfactorily accounted for by the presence of a little chalcocite in the mineral. Dr. H. E. Merwin in an independent microscopic examination estimated the amount of the chalcocite as 2 to 3 weight per cent. Calculated on the basis of the copper determination, which is very exact, and assuming the formula of bornite to be Cu_5FeS_4 , the quantity of the chalcocite is found to be 3.45 weight per cent. If we take 5.076 as the specific gravity of pure bornite and 5.8 as that of pure chalcocite,* the percentage of chalcocite in a mixture having a gravity of 5.103, becomes 4.22 per cent. Finally, if we assume the copper determination to be exact and accept the formula Cu_5FeS_4 , we calculate the gravity of the bornite present to be 5.074. There can, therefore, be no reasonable doubt that all the specimens I have analyzed are essentially identical and are well represented by the formula Cu_5FeS_4 .

My conclusion as to the composition of bornite consequently coincided with Harrington's, and I had no intention of publishing these results separately until several other papers appeared on the subject, in all of which the authors presented different views.

In the number of this Journal for June, 1914 (vol. xxxvii, p. 539), Kraus and Goldsberry, while admitting that some bornites have the composition Cu_5FeS_4 , maintain that other specimens have a different composition, as did Cleve years ago. They submit in evidence two analyses made by them on the bornite crystals from Bristol, Connecticut. The analyses follow:

	I	II	Average
Cu	65.42	65.91	65.665
Fe	9.74	9.67	9.705
S	24.79	24.51	24.656
	<hr/> 99.95	<hr/> 100.09	<hr/> 100.020

Kraus and Goldsberry state, regarding the material for these analyses, that they used portions of two different specimens, viz: 4 and 1. No. 4 consisted of an aggregate of cubical crystals.

* Posnjak, Allen and Merwin, *The Sulphides of Copper*, *Economic Geology*, x, 491, 1915.

ANALYSIS OF NATURAL BORNITES.

Locality	Superior, Arizona	Unknown	Costa Rica	Bristol, Conn.	Guilford Co. N. C.	Messina, Transvaal	Cal. for Cu ₂ FeS ₄
Cu	62.99	63.19	63.08	63.26	63.90	63.24	63.33
Fe	11.23	11.31	11.22	---	10.79	11.12	11.12
S	25.58	25.44	25.54	---	25.17	25.54	25.55
Pb	.10	none	none	---	none		
Ag	none	.02	none	---	none		
Total gangue ¹ practically all quartz	99.90	99.96	99.84	about .03	99.86	99.90	100.00
Mineral at 25° ²	5.076	5.076	5.052	5.079 ³	5.103	5.094	
Water at 25°							
Mineral at 25° Cal.	5.061	5.061	5.037	5.064	---	5.079	
Water at 4°							

¹ As bornite generally tarnishes readily, it was thought best not to powder the specimens; they were generally broken up into rather coarse grains and, since the gangue was not quite evenly distributed it was determined in each portion where the results would be appreciably affected by this inhomogeneity. The bornite from Messina, Transvaal, was first sized between screens of 100 and 125 mesh to the inch.

² These values were determined by the pycnometer. They were corrected for the volume of quartz the specimens contained; vacuum corrections were also made.

³ Harrington's value was 5.073 at 15° which is equivalent to 5.079 at 25°, identical with my result.

tals which were "covered with a dark-colored coating which was thoroughly removed before the material was crushed for analysis." "The material from specimen 1 was the lower portion of the crystal represented by fig. 1." "The material was, as far as could be determined by the ordinary methods, homogeneous in every respect. This was later substantiated by a careful metallographic study of specimen 1." That is, No. 4 was not examined metallographically at all, and only the basal portion of No. 1 was so examined. This was unfortunate, since the *basal portion* of sulphide crystals has been found to be especially liable to contain impurities.* The authors admit that a part of the bornite from this same locality (Bristol, Conn.) has the composition Cu_5FeS_4 , as their analyses of a fragment of specimen 805 of the Brush Collection at Yale University showed. This was one of the specimens analyzed by Harrington.

Through the kindness of Professors Dana and Ford another fragment of specimen 805 was sent to us. It was examined microscopically by Dr. H. E. Merwin, who reported that seven out of eight pieces of this fragment were practically pure, while the eighth contained about 30 volume per cent of chalcocite!

On the basis of the two analyses quoted above and ancient analyses found in the literature, Kraus and Goldsberry set up a long series of copper-iron-sulphide compounds between Fe_2S_3 and Cu_2S . More recently two other articles† have appeared on this subject, in both of which the evidence of Kraus and Goldsberry is accepted, though other explanations are advanced for it. But since these writers bring forward no new evidence, it will hardly be necessary for us to consider their hypotheses.

For the sake of completeness, we may include here a recent analysis of the bornite from Virgilina, Virginia, by Chase Palmer.‡ Palmer's material was examined metallographically

	Found	Cal. for Cu_5FeS_4
Cu	62.50	63.33
Fe	11.64	11.12
S	25.40	25.55
	<hr/> 99.54	<hr/> 100.00

and it is noteworthy that the principal impurity was chalcopyrite. Though the results are in a fair agreement with Cu_5FeS_4 , "the relatively high proportion of iron suggests the presence

* Murdoch, loc. cit., p. 36.

† A. F. Rogers, *Science*, xlii, 386, 1915; E. T. Wherry, *ibid.*, p. 570.

‡ J. Wash. Acad. Sci., v, 351, 1915.

of a small quantity of chalcopyrite which in preparing the sample for study has escaped detection."

Finally, observations of two physical properties of bornite confirm the chemical evidence. Murdoch* states that "the mineralographic examination of polished surfaces of bornite from at least 30 different localities has revealed only an exceedingly slight variation in color and practically none in microchemical behavior." While reliance on density *alone* as a criterion of purity is unsafe, the determinations in the table (p. 411) are confirmatory. All the determinations are in good accord (5.061 to 5.079) except that on the Costa Rica specimen; and while it may be possible that we have here another crystalline form of the same composition, the low value for this bornite is reasonably accounted for by Dr. Merwin's observation, viz.: that under the microscope it has a porous appearance.

Aside, then, from those slight variations in composition which are so common throughout the mineral kingdom, and which are due to foreign admixtures or to solid solution, there is, in my opinion, no satisfactory evidence that natural bornite is variable in composition, or that it is ever of any other composition than that expressed by the formula Cu_5FeS_4 .

I wish to express my thanks to Dr. H. E. Merwin for metallographic analyses; to Drs. George P. Merrill and E. T. Wherry of the National Museum; and to Professors Dana and Ford of Yale University, for specimens of bornite; and also to Professor Gratton of the Harvard Mining School for specimens which had been carefully examined metallographically.

* Loc. cit., p. 35.

Geophysical Laboratory
Carnegie Institution of Washington,
Washington, D. C., March 22, 1916.

ART. XXX.—*Further Study of the Interference of Reversed Spectra*; by CARL BARUS.*

1. *Apparatus with one grating.*—The different methods suggested in the preceding papers† were each tried in succession, but none of them were found equally convenient or efficient in comparison with the method there finally used. To begin with the annoyance encountered in the use of a reflecting grating, it was found that the impinging light from the collimator and the reflected doubly diffracted beam from the grating, lie too close together, even if all precautions are taken, to make this method of practical value. The use of Rowland's concave grating without a collimator is out of the question, since the spectra formed on the circular locus of condensation, if reflected back, will again converge into a white image of the slit, colored if part of the spectrum is reflected. The plane reflecting grating, though not subject to this law, requires a collimator, and since marked obliquity of rays is excluded, it will hardly be probable that the elusive phenomena can be obtained in this way. A compromise method, in which *both* the reflecting and the transmitting grating are used, will be described in § 4. Though apparently the best adapted of all the methods used, it has only after difficult and prolonged research led to results. These, however, proved very fruitful in their bearing on the phenomena.

For first order spectra, where there is abundance of light (it is often difficult to exclude all the whitish glare in the field of the telescope completely), the method of fig. 1, which shows normal rays only, is still preferable. Here the impinging collimated beam L passes below the opaque mirror m and through the lower half of the grating G . The diffracted pencil is reflected nearly normally but slightly upward, by the mirrors M and N (the former carried on a micrometer slide); to be again diffracted at the grating and therefore to impinge as definitely colored light on the lower edge of the concave mirror m (about 1.5 to 3 meters in focal distance), whence it is brought to a focus at F and viewed by the strong eyepiece E . Considerable dispersion and magnification is obtained in this way; indeed, the two D lines stand far apart and the nickel line is distinctly visible between them. There must be a fine-hair wire across the slit so that the longitudinal axes of the spectra may be accurately adjusted. The mirror m above the impinging beam must be capable of rotation about a vertical and a

* Abridged from a forthcoming Report to the Carnegie Institution of Washington, D. C.

† This Journal, xl, pp. 486–498, 1915.

horizontal axis, in order that the focus F may be appropriately placed between M and N : with G at one meter and m at two meters from F , the disposition is good. The micrometer M is easily at hand. Though the direct beam may be screened off, the glare reflected back from the grating and the glare from the objective of the collimator are not excluded, as stated. In fact it was eventually found necessary to carry this pencil in an *opaque tube* reaching from the objective of the collimator, as far as the grating.

Second order spectra are too faint and cannot be seen, unless the glare is excluded in the manner stated.

An alternative method of half silvering the ruled face of the grating and then using it as a reflector, was tried with success. The beam of parallel rays from the collimator L , fig. 2, are transmitted by the grating (ruled, half-silvered face, g toward the mirrors M and N) and the two diffracted beams then returned by the opaque mirrors M and N , to be in turn diffracted by reflection, into the telescope T . The stationary interferences are practically absent, while two strong spectra are reflected from the silvered side. The phenomenon may then be produced at all distances of G from M and N (two meters and less), but best at distances within one meter.

Besides the symmetrical position, gT , fig. 2, the two corresponding unsymmetrical positions, $g'T'$, were tested with success, but dark lines are apt to be broadened.

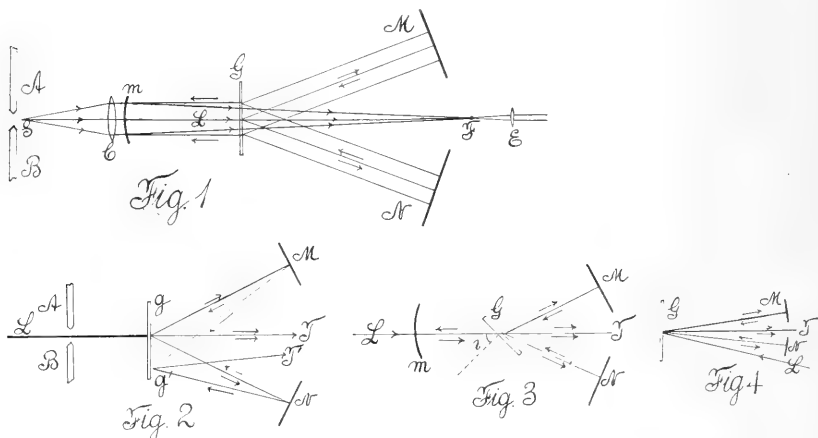
Questions relative to the effect of oblique incidence were also tested by aid of the concave mirror method shown in fig. 1, the white light from C to G being conducted in an inch tube of pasteboard, immediately under the concave mirror m . Figure 3 gives the general disposition of apparatus. The angle of incidence i is gradually increased, until the return rays from N meet the grating at nearly grazing incidence. No essential difference in the phenomenon was observed, however, except that it was apt to be broader in the non-symmetrical positions and to suggest fine new lines in parallel with the old. On broadening the slit the black lines vanish first and a flickering band remains after the Fraunhofer lines are gone. Finally the phenomenon could be seen even when the longitudinal axes of the spectra were not quite coincident, but it rapidly became fainter in intensity.

Figure 4 suggests a method of using a reflecting grating, either plane or (possibly, if the incident light is parallel) concave, for the production of the phenomenon. G is the grating, receiving the collimated white light, L , which is diffracted toward M and N , thence reflected (at a different elevation) back to G , to be again diffracted towards T , above or below the direct beam, where it is observed. I have not, however,

been able to obtain results with these methods owing to subsidiary difficulties.

2. *Observations and experiments with a single grating.*—On considering fig. 1, it will be seen that the doubly reflected, doubly diffracted rays, are also in a condition to interfere. Thus the rays $GMGN$ and $GNMG$ have identical path length, or at least of path difference. It is improbable, however, that superimposed on the strong spectra, this effect could be seen, and the inferences relatively to a phenomenon produced by double diffraction would not be modified.

FIGS. 1-4.



Many experiments were made to ascertain the path difference within which the phenomenon is visible but led to no new results; i. e., the limiting distances of visibility along the ray are 15,000 to 30,000 wave lengths apart, about as estimated in the preceding paper. This is the characteristic feature of the phenomenon. It is visible for a wide slit even after the Fraunhofer lines vanish. It disappears by decreasing in width, when the slit is closed. If the ocular of the telescope is drawn out, the phenomenon may even be observed after the Fraunhofer lines have vanished, in the dark stringy spectrum of an extremely fine slit.

Since the phenomenon was originally produced with sunlight, it might be supposed that the *edges* of the Fraunhofer line under conditions of tremor would interfere with each other. The crucial test was made by using an arc lamp spectrum, and it was then found that the phenomenon appeared as well as with sunlight.

A further question at issue is the breadth of spectrum needed

to produce the phenomenon, for the observed breadth would be influenced by the quiver of the apparatus. With this end in view different lines of the spectrum were placed in full coincidence. For none of the secondary lines in the orange-yellow was it extinguished or even modified. If, however, $D_1 D_1'$ or $D_2 D_2'$ were superposed, the phenomenon played like a wavy strip at their edges only. Sometimes a bright line flashed through the middle of the coincident lines. One may conclude, therefore, that the part of the mutually reversed spectra used in producing these interferences, is not much broader than either the D_1 or D_2 lines, while the other marked lines in the orange-yellow are too narrow to appreciably influence it. These results will be greatly amplified in the work done with two gratings below.

A corresponding experiment was now made with *sodium light*. To obtain a sufficiently intense source, solid caustic soda was volatilized between the carbons of the electric arc, *A* and *B*, fig. 1 or 2. On drawing the carbons apart, strong D lines were seen (in the entire absence of an arc spectrum), at first so broad as to be self-reversing. Gradually they became finer and eventually reached the normal appearance of the D_1 , D_2 lines. In order to facilitate adjustment and with the object of obtaining cases correlative with the results for the dark line spectrum, a beam of sunlight (as at *L*, fig. 2) was introduced between the carbons and the phenomenon established faultlessly in the usual way. The pencil of sunlight was then screened off and the arc light substituted, or the two were used together.

These observations seemed to show that when the normal D_1 or D_2 lines were placed in coincidence, the thread-like phenomenon does not appear with all the characteristics visible in the case of sunlight. When the slit is broadened an alternation of brightness, or flicker of light, may be detected, vaguely. With a slit of proper width to show the Fraunhofer lines all this seemed to vanish. The actual phenomenon was therefore apparently not reproduced or improved either by homogeneous light or by widening the slit. Such experiments alternating with sunlight were made at considerable length, but the adaptation of methods for two gratings discussed in § 4 will nevertheless modify this conclusion.

If the narrow sodium line is broadened by adding fresh sodium at the carbon, so that the yellow spectrum is again self-reversed, the phenomenon plays with extreme vividness around either of the reversed and coincident D_1 or D_2 lines or even within the black line in question, if narrow. But here the light is no longer homogeneous.

3. *Inferences*.—If the wave length of the two spectra is laid off in terms of the angle of diffraction, θ , measured in the

same direction in both cases, the graph will show two loci intersecting in the single point of coincident wave lengths λ_0 . It appears, however, as if the wave lengths near λ_0 are still in a condition to interfere. The phases differ because of path difference introduced at the micrometer, for instance, and because of color differences, the rays having passed through refracting media of glass and air.

As instanced in the earlier paper, if ten beats per second are discernible, the beating wave trains in the case of the given grating would only be 6×10^{-10} second of arc apart in the spectrum. If the phenomenon has a breadth of 3×10^{-8} cm. in wave length (as observed), then the number of beats in question will be 2.5×10^{11} per second. All this is out of the question. If beats were due to a difference of *velocity* resulting from the dispersion of air and if T is the period of the beats, λ the mean wave length, $\delta \frac{1}{\mu}$ the difference of the reciprocal indices of refraction, we may write

$$T_1 = \frac{\lambda}{v \delta (1/\mu)}.$$

If furthermore $\mu = A - B/\lambda^2$, where $B = 1.34 \times 10^{-14}$, $\delta \lambda = 2.4 \times 10^{-8}$

$$T_1 = \frac{\lambda^4}{2vB\delta\lambda}$$

or $N_1 = 1.4 \times 10^6$ beats per sec., which would also be inappreciable.

If both the difference of wave length and wave velocity are considered the visibility of the phenomenon is not changed, as the first frequency is very large compared with the second.

The occurrence of *forced vibrations* has also been looked to as an explanation. Though here again, even if the spectra are almost always of unequal intensity, the reason for the preponderance of one would have to be stated. In the case of forced vibrations (in the usual notation) if there is no friction, the resulting harmonic motion will be given by

$$y = \frac{A}{q^2 - p^2} \cos pt.$$

On one side of the line of coincidence λ_0 , $q^2 > p^2$; on the other side $p^2 > q^2$. Hence whenever a brilliant line flashes out due to coincident phases, there should also be a black line due to opposition; and, in fact, when the phenomenon is produced under conditions of perfect symmetry of the component beams,

this seems to be its character; i. e. the enhanced doublet cuts vertically across the breadth of the spectrum. It is not to be overlooked, however, that in certain adjustments, particularly in the non-symmetrical case of figure 3, more than two black lines frequently occur. Again, the presence of many oblique lines will be shown in § 4 and 8. These would be quite unaccounted for.

Finally, many attempts were made to find whether the phenomenon would occur again beyond its normal range of about $2 \times .5^{\text{cm}}$ of displacement. But though the micrometer screw actuating the mirror M was effectively $2 \times 3^{\text{cm}}$ long, no recurrence could be found. At the ends of its range the phenomenon drops off rather abruptly.

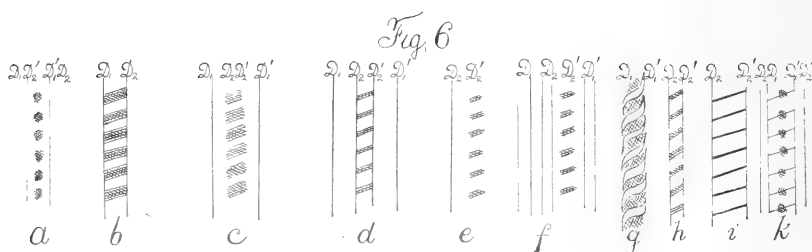
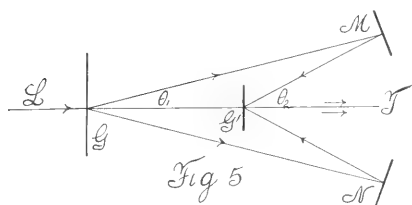
Hence none of the inferences put forward adequately account for the phenomenon (even as seen with a single grating) as a whole. One feature, it is true, has been left without comment and that is the width of the slit image since within the limits of the present method of experiment, with but one grating, this circumstance seems to offer no clue. If, for instance, the spectra actually coincide in color throughout their extent, as in ordinary interferences, the interference patterns should be *enormous*, for the path difference may be zero. The invariability of the present phenomena as to size within its long range of presence, the occurrence of intensely sharp and bright or dark single lines, within a breadth of spectrum much less than the distance apart of the D_1, D_2 lines, is in no way suggested by the width of slit image. Moreover in spite of its persistence, the interference phenomenon of reversed spectra has the *sensitiveness* of all interferences. Slight tapping on the massive table throws it out altogether. Clearly therefore, a modification of method is essential if new light is to be thrown on the phenomenon, and from this viewpoint, a *separation* of the two diffractions seems most promising.

4. *Apparatus with two gratings.*—All the varied experiments described in the preceding paragraph failed to show any essential modification of the linear interference pattern obtained. It therefore seemed promising to modify this limitation of the experiments, although the difficulty of finding the phenomenon would obviously be greatly increased.

In the present method the glass grating G , fig. 5, receives the white beam L from the collimator. This light is then diffracted to the opaque mirrors M (on a micrometer slide) and N , thence reflected to the reflecting grating G' , plane or curved. Here the two beams of the identically colored light selected are again diffracted to the telescope or lens at T . Since the gratings G, G' rarely have the same grating constant, their proper position must be found by computation and

trial. In my case the distances to the line of mirrors NM were 165^{cm} for G and 90^{cm} for G' . This method automatically excludes the direct beam and all glare and gives excellent spectra, both in the first and second orders. The use of two gratings, however, introduces the difficulties of adjustment specified, as the two D doublets corresponding to N and M will not as a rule be parallel and normal to the longitudinal axes of the spectrum, unless all cardinal features (like the

FIGS. 5, 6.



rulings and their planes) are quite parallel. If the grating is not normal to the impinging beam, the axes of the corresponding spectrum is a curved line. As a result I was not, in my earlier work, able to produce the phenomena with two gratings, after many trials, in spite of the clearness of the overlapping spectra.

Later, having added a number of improvements to facilitate adjustments, I returned to the search again and eventually succeeded. There are essentially four operations here in question, supposing the grating G approximately in place. By aid of the three adjustment screws on each of the mirrors M and N , figure 5, the fine wire drawn across the slit may be focussed on the grating, if an extra lens is added to the collimator and the black horizontal shadows of that wire, across the corresponding spectra, placed in coincidence. The grating G' is then to be moved slowly fore and aft, normal to itself, on the slide, so that the position in which the sodium lines are

nearly in coincidence to an eye placed at the telescope T may be found. The grating G' is next to be slowly rotated on a line (parallel to LT) normal to its surface, to the effect that the black axes of both spectra (i. e., the spectra, as a whole) may coincide. This must be done *accurately* and the last adjustments may be made at the screws controlling M and N . Finally the micrometer slide carrying M is to be moved fore and aft, until the interferences appear. These operations are difficult even to an experienced observer. The new fringes are very susceptible to tremor and only under quiet surroundings do they appear sharply. At other times they move, as a whole, up and down and intermittently vanish.

The fringes so obtained, figure 6, were totally different from the preceding and consisted of short black equidistant nearly horizontal lines across the active yellow strip of spectrum at the axis of coincidence. The strip was about of the same width as above. Thus the pattern presented the appearance of a barber's pole in black and yellow, the width being less than D_1D_2 and the distance apart of fringes usually smaller. Since the fringes were as a rule nearly horizontal, it was possible to enlarge the width of the slit without destroying them as in case of the hair-like vertical fringes in paragraph 2 above. In this way a breadth of strip greater than the distance D_1D_2 could be obtained with sunlight or arc light, though a moderately fine slit was still desirable.

In general the characteristics noted above were again observed. Thus on moving the micrometer screw controlling M , the interferences appeared rather abruptly and vanished in a similar manner after about 4^{cm} or more of the micrometer screw (15,000 wave lengths) had been passed over.

If we called the four D lines available in the two solar spectra $D_1D_2, D_1'D_2'$, respectively, a number of curious results were obtained on placing them variously in approximate coincidence. Thus figure 6 *a*, when each D line of one spectrum coincides with the mate of the other ($D_1D_2'; D_1'D_2$), equidistant dots, surrounded apparently by yellow luminous circles, appeared between the two doublets. On widening the slit the dots changed to a grid of nearly horizontal lines covering the strip D_1D_2 , figure 6 *b*. Often the lines in part of the slit seemed to slope upward and in another to slope downward.

The phenomenon of chief interest, however, was observed (fig. 6 *c*) in placing two identical D lines of the solar spectrum in coincidence ($D_1; D_2D_2'; D_1'$). The fringes were then seen across the coincident lines, now no longer visible as such, quite independent of the absence of light. This would seem to mean that the otherwise quiet ether within the black line

is stimulated into vibration by the identical harmonic motions of the bright fields at and beyond the edges of the line. The question will presently be broached again in a different way. Here I may note that in the above cases of transverse lines (§ 2), it is often possible to observe a very fine parallel yellow line within the coincident D_2D_2' or D_1D_1' doublets, excited therefore in the dark space and splitting the line.

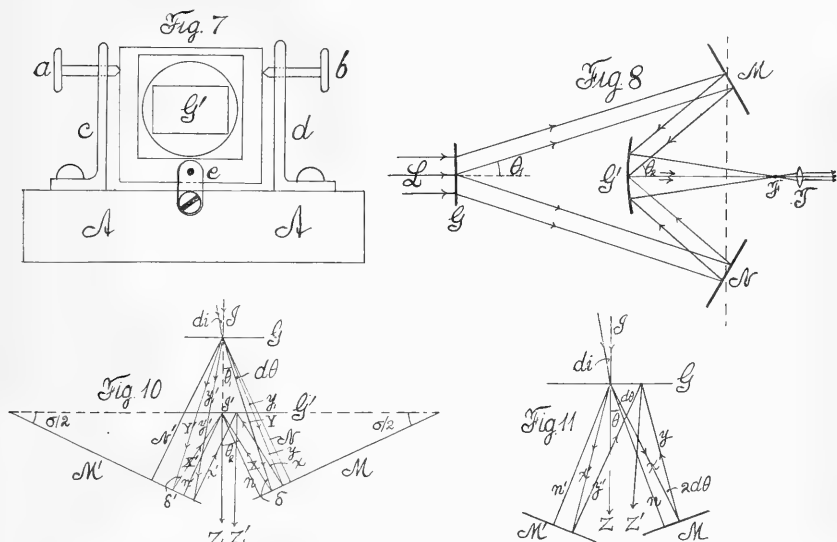
The experiments were now repeated with the *sodium arc* and these also gave some striking results. Thus in the case of figure 6 *d* the lines were separated, but the yellow striations seemed to play across the dark space between D_2D_2' . When the yellow light was too weak, cross hatchings were only seen across D_2' as in the figure 6, *e*. Frequently the phenomenon, figure 6 *f*, occurred on broadening the slit, in which D_2 and D_2' interfered, but only D_2' was marked. Screening off D_2 (left mirror) at once removed the fringes. I have interpreted this observation as the result of parallax, due to the fact that the lines and the interferences are seen in different focal plans.

On the basis of these results one might argue with some plausibility that identical wave trains react on each other across an ether gap, small as compared with the D_1D_2 interval. In such a case, moreover, the assumption made in the earlier paper relative to interference of different wave lengths, is superfluous. My misgiving in the matter is the misfortune that having taken down the original apparatus, for modification, I have since been unable to reproduce them with anything like the decisiveness with which they were at first apparently observed. I cannot now be certain whether what occurred was actually what I seemed to see, or whether the broad illumination of the sodium flash (broadened individual lines, D_1 to D_2 , virtually a continuous spectrum) may not have misled me; or whether different focal planes were in question.

6. *Experiments continued: New Interferometer.*—At the onset it was necessary to ascertain the reason for the difference of the phenomena, as obtained with one grating in paragraph 3, and with two gratings in paragraph 5. Since the probable cause is a lack of parallelism of the rulings in the latter case, it was necessary to remount the second grating G' in the manner shown in fig. 7. Here AA is a base board, capable of sliding right or left and of rotating on a horizontal axis parallel to the grating. The latter (in a suitable frame) is held at the bottom by the axle, *e*, normal to the grating and by the two set screws *a* and *b* carried by the standards *c* and *d*. Thus the grating could be rotated around an axis normal to its plane. At first a Michelson plane reflecting grating G' and a telescope were used as in fig. 5, but it was found preferable (fig. 8) to use a

Rowland concave reflecting grating G' with the strong lens at T , the grating receiving a beam of parallel rays of light for each color from the collimator and first grating G . In this case, with sufficiently high dispersion, a large strong field was obtained, in which even the very fine lines of the solar spectrum were quite sharp. Rotating the grating G' around a parallel horizontal axis, like AA , made little difference, relatively speaking; but rotation around the axis e normal to its

FIGS. 7, 8, 10, 11.



plane, carried out by actuating a and b in opposite directions, made fundamental differences in the appearance of the phenomenon and eventually suggested a new interferometer for homogeneous light.

The adjustments are the same as in case of fig. 5 (G being the transparent grating) except that G' is now a concave grating, and T a strong eyepiece. The distances $G'T$ and GT were of the order of one and two meters. The first experiments with the new and powerful apparatus (plane transparent grating G , grating space 351×10^{-6} cm., and the concave reflecting grating G' , grating space 173×10^{-6} cm., fig. 8) were made with the object of verifying, if possible, the reaction of parallel ether wave trains on each other across a very narrow ether gap. The sodium arc lamp was used as a source of light. The results as a whole were negative, or at least conflicting. When the

lines are self-reversed, superposition of D_1D_1' , etc., frequently showed vivid interferences across the intensely black middle line. This, and the passage of the bright and dark lines across the superposed D_1D_1' lines of the solar spectrum are thus the only evidence of the reaction of separated light rays on each other across an ether gap observed in the new experiments.

An additional series of experiments was made some time later by *screening* off parts of the concave grating G' , in order to locate the seat of the phenomenon at the grating. Screening the transmitting grating G was without consequence; but on reducing the area G' to all but the middle vertical strip about five millimeters wide, a very marked intensification of the phenomenon followed. Although the spectrum as a whole was darker, the interferences stood out from it, relatively much sharper, stronger and broader than before. The Fraunhofer lines were still quite clear. Thus the pattern g , fig. 6, was now very common, both with sunlight and with sodium light. For a given slit the phenomenon began with a strong burr c , fig. 6, completely obliterating and widening the superposed D_2D_2' lines. When these lines were moved apart, the striations followed them, as in fig. 6, h and i , to a limit depending on the width of the slit. A still more interesting pattern is shown in fig. 6, k , in which the interferences proper are strong and marked between the D_1D_1' doublets, but much fainter striations are also evident reaching obliquely across and obviously with the same period. With this improvement I again tested the ether gap phenomenon, using the sodium arc, and to my surprise again succeeded. Several days after, however, with another adjustment, it in turn failed. Clearly there is some variable element involved that escaped me, and it will hardly be worth while to pursue the question further with the given end in view without a radical change of method.

A word may be added in relation to Fresnellian interferences in the present work. These would be liable to occur if the observations had been made *outside* of the principal focus with the sodium lines blurred. In all the experiments on the excitation of a narrow ether gap, however, the D lines were clearly in sight and sharp, so that the phenomena of non-reversed spectra and homogeneous light (discussed elsewhere) are not here in question. True, such interferences may often be found in the case of reversed spectra, when the sodium lines are purposely blurred by pushing the ocular toward the front or to the rear.

6a. *Experiments continued.*—To turn to a second-class of experiments; important results were obtained with homogeneous light (sodium arc) on placing the D_1D_1' or D_2D_2' lines in coincidence and then broadening the slit indefinitely, or

even removing it altogether. A new type of interferences appeared, linear and parallel in character and intersecting the whole yellow field. These lines could (as above) be made to pass from a grid of very fine hair-like nearly horizontal lines to relatively broad vertical lines, on changing the orientation of the grating G' , figure 5 or 8. Small changes of position of the grating produced a relatively large rotation and enlargement of the lines of the interference pattern. The fringes when vertical and large are specially interesting. The distances between successive fringes obtained were about the same (accidentally) as the D_1D_2 distance of the sodium lines. They are quiet in the absence of tremor. If D_1D_1' or D_2D_2' were only present, the field would be an alternation of yellow and black striations. The fringes are nevertheless quite distinct, but a single homogeneous line (like the green mercury line) would give the best results. It is necessary that the line selected (say D_1D_1') should coincide horizontally and vertically before the slit is broadened. Otherwise no fringes appear in the yellow ground or at least not in the principal focal plane. On using a thin mica compensator, it is easy to control these fringes while the mica film is rotated. The fringes remain identical in size, from their inception till they vanish, while the micrometer M , figure 5, passes (as above) over about 15,000 wave lengths. In this respect the new interferometer differs from all other types, the actual lengths of the two air paths GMG' , GNG' alone being in question.

7. *Experiments continued.*—As these fringes were produced with a concave reflecting grating, the question may be put whether they would also appear in case of the plane reflecting grating, G' , in the adjustment of figure 5. The experiment was therefore repeated with a wide slit, or with no slit at all, and there was no essential difference in the two classes of results.

On the contrary, when the method of but one grating and sodium light was used (figure 1) the interferometer fringes, in case of a very wide slit or the absence of a slit, could *not* be produced over the yellow field, as a whole. There appeared, however, an obvious flicker in parts of the field, on reducing the width of the slit till the sodium lines were each about the width of a D_1D_2 space, with either D_1D_1' or D_2D_2' superposed. The sharply outlined slit showed an irregular rhythmic brightening and darkening over certain parts of its length. These broad pulsations were very violent, very much in character with the linear phenomenon above.

Regarding the phenomenon as a whole, one may argue that in case of the wide slit and single grating, in which the lines for both diffractions are therefore rigorously parallel, the in-

interference fringes are on so large a scale as to cover the whole field of view and thus to escape detection; i. e., that a *single vague quivering shadow* of a flickering field is all that may be looked for, in the limited field of view of the eyepiece.

Returning to the case of two gratings and the wide vertical interference fringes and in turn all but closing the slit (vertical interferences and sodium arc light), the pulsating phenomenon simply narrowed in width. The two or three sharp vibrating lines, alternating in black and yellow, of the phenomenon described in the earlier paper, did not appear.

7a. *Experiments continued.*—The method of two gratings (figure 5 or 8, plane transmitting and concave reflecting) was first further improved by perfecting the fore and aft motion of the grating G' (G' movable in the direction $G'T$, on a slide), as well as the precision of the independent rotation of G' normal to its face, i. e. around $G'T$. These adjustments lead to a further interpretation of the phenomenon. To begin with, the *fore and aft motion* of the concave grating G' (i. e., displacements in the directions $G'T$, figure 8), it was found that the fringes, figure 9, *abcde*, in any good adjustment, pass from extremely fine sharp vertical striations, which gradually thicken and incline to relatively coarse horizontal lines, finally with further inclination in the same direction into fine vertical lines again, while G' continually moves (through about 5^{cm}) on the slide normal to the face of the grating. It was not at all difficult to follow the continuous tilt of these lines through the horizontal, occurring on careful and continuous front and rear motions of the grating G' through the limiting positions. The fringes usually vanish vertically merely because of their smallness.

Again on *rotating* the grating G' around an axis normal to its face, the fringes merely vary in size, without changing their inclination. Thus if the horizontal fringes (which were here always closer than the inclined set) are in view, these will pass from extremely small size, fine hair-like striations, through a maximum (which is a mere shadow as a single fringe probably fills the field), back into fine lines again. Only a few degrees of rotation of the grating suffice for the complete transformation. The maximum is frequently discernible only in consequence of a flickering field. An oblique set of fringes is equally available, remaining oblique as they grow continually coarser and in turn finer with the continuous rotation of the grating.*

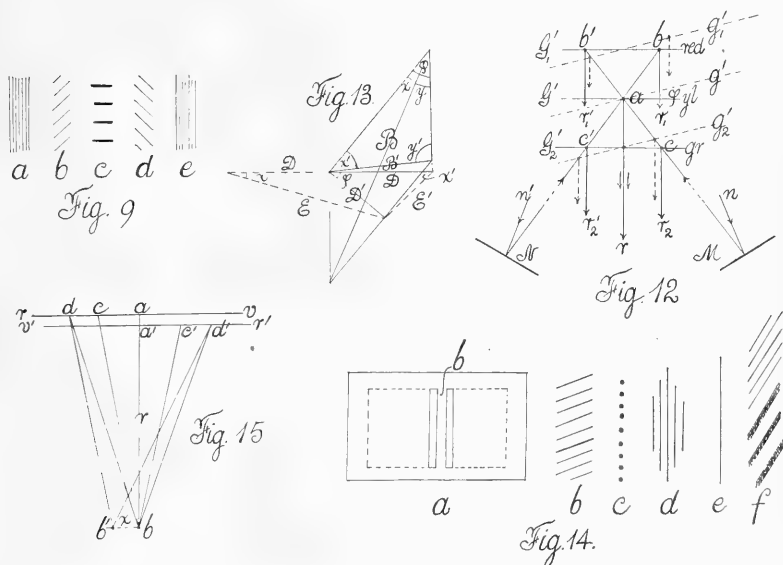
When the very large horizontal fringes are produced by this method, the change into vertical fringes by fore and aft motion

* Recent work showed that rotations of fringes with passage through maximum size are also producible here. The subject will be resumed.

of G' is very rapid, so that relatively wide nearly vertical forms may be obtained. All these effects may be produced by solar or by arc light around the line of symmetry of the overlapping spectra, or with sodium light when either D_1D_1' or D_2D_2' coincide.

The fine vertical or inclined lines appear as such when the slit is widened, either in case of white or of sodium light. These are the interferometer fringes seen above (§6), coarse or fine. With sodium light any width of slit or no slit at all

FIGS. 9, 12, 13, 14, 15.



are equally admissible. The same is true for the narrow maxima.

Finally (and this is the important result) the extremely large horizontal maxima, when a single fringe fills the field, cannot be seen apart from pulsations, in the case of a wide slit. With a very narrow slit such as is suited for the Fraunhofer lines, these *horizontal fringes appear as intensely bright or very dark images of the slit*. In other words, the normal phenomenon of overlapping symmetrical spectra as described in the earlier paper, is merely the vertical strip of an enormous horizontal interference fringe, made sharp and differentiated by its narrowness. This case occurs at once when the rulings of the two gratings G and G' are all but parallel and hence it is the regular phenomenon when but a single grating is used for the two diffractions, as in figure 1.

This explanation shows why the original phenomenon, consisting of single lines, cannot be manifolded by increasing the width of slit. It vanishes for a wide slit into a flickering shadow. The phenomenon is a strip cut across an enormous black or bright horizontal fringe, by the occurrence of a narrow slit. Moreover the scintillations variously interpreted above are now seen to be due to tremors, however different from such an effect they at first appear; i. e., the enormously broad horizontal fringe changes from dark to bright, *as a whole*, by any half wave length displacement of any part of the apparatus.

To be quite sure that the concave grating G' had no fundamental bearing on the phenomenon, I again replaced it by the Michelson plane reflecting grating with similar results.

8. *Equations.*—An attempt must now be made to describe the phenomena, or at least the interferometer part of them, by equations. This may be done for the method of two gratings at once, as the result, if the distance apart of the gratings is $C=0$, includes the method with one grating; i. e., the more complicated figure 10, where G is the transmitting and G' the reflecting grating, resolves itself into a case of figure 11 with but one grating, G . M and M' are the two opaque mirrors, I the normally incident homogeneous ray. Supposing, for simplicity, that the grating planes, G and G' , are parallel and symmetrically placed relatively to the mirrors M and M' , as in the figure, the ray Y diffracted at the angle θ_1 is reflected into X at an angle $\delta = \theta_2 - \theta_1$ and diffracted into Z normally, at an angle θ_2 , on both sides. Under the condition of symmetry assumed

$$X + Y - (X' + Y') = 0$$

or without path difference. Let N be the normal from I to M , and n the normal from I' to M' , with a similar notation on the other side. Hence if I be given an inclination, di , θ_1 is incremented by $d\theta_1$, $Y + X$ passes into $y_1 + y + x$, $Y' + X'$ into $y' + x' + x'$, decremented at an angle $d\theta_1'$, while both are diffracted into Z' . Since generally

$$\frac{\sin \theta_1 - \sin i}{\cos \theta_1 d\theta_1} = \frac{\lambda/D}{\cos \theta_1' d\theta_1'}$$

for homogeneous light and the same di . Hence $d\theta_1 = d\theta_1' = d\theta$. If

$$\delta = \theta_2 - \theta_1, \quad \sigma = \theta_2 + \theta_1$$

the auxiliary equations

$$X + Y = C \frac{\sin \theta_1 + \sin \theta_2}{\sin \delta},$$

and

$$C = \frac{N - n}{\cos(\sigma/2)},$$

are useful.

With these postulates, the path difference ΔP , after a somewhat cumbersome reduction, finally becomes

$$\Delta P = \frac{N \cos \sigma + n}{\cos(\sigma/2)} \frac{2 \sin \theta_2}{\cos^2 \theta_2} d\theta,$$

nearly. Hence the angular breadth of an interference fringe would be ($\Delta P = \lambda$)

$$d\theta = \frac{\lambda \cos^2 \theta_2}{2 \sin \theta_2} \frac{\cos(\sigma/2)}{N \cos \sigma + n};$$

and if D is the grating space and $\sin \theta = \lambda / D'$,

$$d\theta = \frac{(D'^2 - \lambda^2) \cos(\sigma/2)}{2 D' (N \cos \sigma + n)}.$$

In case of a single grating $\sigma/2 = \theta_2 = \theta$, $N = n_1 \cos \sigma = 2 \cos^2 \theta - 1$, or

$$\Delta P = \frac{2 N \cos^2 \theta}{\cos \theta} \frac{2 \sin \theta}{\cos^2 \theta} d\theta = 4 N \tan \theta d\theta,$$

a result which may be reduced more easily from figure 11. Hence if the angular distance apart of the fringe is ($\Delta P = \lambda$)

$$d\theta = \frac{\lambda}{4 N \tan \theta} = \frac{D \cos \theta}{4 N} = \frac{\sqrt{D^2 - \lambda^2}}{4 N}$$

if D is the grating space. To find the part of the spectrum ($d\lambda$) occupied by a fringe since $\sin \theta = \lambda / D$

$$\frac{d\theta}{\cos \theta} = \frac{d\lambda}{D \cos^2 \theta} = \frac{D}{4 N}, \text{ and}$$

from the preceding equations, finally,

$$d\lambda = \frac{D^2 - \lambda^2}{4 N}$$

where $d\lambda$ is the wave length breadth of the fringe, remembering that the fringes themselves are homogeneous light.*

In the grating used, $D = 351 \times 10^{-6}$ cm., $\lambda = 60 \times 10^{-6}$ cm., $n = 100$ cm., or $d\lambda = 3 \times 10^{-10}$ cm. This is but 1/200 of the distance, $d\lambda = 6 \times 10^{-8}$ cm., between the D lines. Hence these fringes would be *invisible*. Moreover, $d\theta \propto 1/N$; the fringes therefore, should grow markedly in size as N is made smaller.

* I shall return to this question elsewhere, the results in the text being in some respects inadequate.

Experiments were carried out with this consideration in view, by the single grating and concave mirror method, N being reduced from nearly 2 meters to 30^{cm}, without any observable change in the breadth or character of the phenomenon. It showed the same alternation on one black and one or two bright linear fringes, or the reverse, throughout. Hence it seems improbable that the phenomenon, or the reverse, i. e., the interference fringes, are referable to such a plan of interference as is given in figure 11.

Similarly for the case of two gratings, figure 10, if the data $\theta_1 = 9^\circ 40'$, $\theta_2 = 19^\circ 55'$, $D' = 173 \times 10^{-6}$ cm., $N = 162$ cm., $n = 82$ cm., $\lambda = 58.9 \times 10^{-6}$ cm. be inserted, $d\theta$ is about of the same value as above.

8a. *Experiments continued.*—With this possible case disposed of, it now becomes necessary to inquire into other causes of the phenomenon, as described in paragraph 7. This is conveniently done with reference to fig. 12, where n and n' are the axes of the pencil of yellow light, reflected from the opaque mirrors M and N , after arrival from the transmitting grating G . It is necessary to consider the three positions of the reflecting grating G' ; viz. G' , G'_1 and G'_2 . In the symmetrical position G' , the pencils whose axes are n and n' meet at a and are both diffracted along r . In the position G'_1 they are separately diffracted at b and b' in the direction r_1 and r'_1 . They would not interfere, but for the objective of the telescope, or in the other case, of the concave mirror of the grating. In the position G'_2 , finally, the pencils n and n' are separately diffracted at c and c' into r_2 and r'_2 and again brought to interference by the lens or concave mirror, as specified.

Now it is true that the rays na and $n'a$ (position G'), though parallel in a horizontal plane, are not quite collimated in a vertical plane. The pencils are symmetrically oblique to a central horizontal ray in the vertical plane and their optical paths should therefore differ. But fringes, if producible in this way, here, have nothing to do with the rotation of the grating in its own plane and may be disregarded.

To take the rotation of the fringes first, the interferences obtained by rotation around a normal axis recalls the common phenomenon observed when two picket fences cross each other at a small angle ϕ , fig. 13. It is interesting to briefly examine the relations here involved when S' and S are two corresponding pickets of the grating at an angle ϕ and the normals D' and D are the respective grating spaces. The intersection of the groups of lines S' and S make the representative parallelogram of the figure (S taken vertical), of which B is the large and B' the small diagonal. The angles indicated in the figure are $x + y = \phi$ and $x' + y' + \phi = 180^\circ$. As the bright band in

these interferences is the locus of the corners in the successive parallelograms, B is the distance between two bright bands, while B' , making an angle y' with S , is the direction of these parallel interference bands relative to the vertical. Let the free ends of D and D' be joined by the line E' ; and if D is prolonged to the left and the intercept is D in length, let this be joined with the end of D' by E . Then the triangle DED' and $S'BS$, $DE'D'$ and $S'B'S$ may be shown to be similar. Omitting the demonstration, the values of B and B' may finally be reduced to

$$B = \frac{E}{\sin \phi} = \frac{\sqrt{D^2 + D'^2 + 2DD' \cos \phi}}{\sin \phi}.$$

$$B' = \frac{E'}{\sin \phi} = \frac{\sqrt{D^2 + D'^2 - 2DD' \cos \phi}}{\sin \phi}.$$

Again the angle y' is on reduction $\tan y' = \frac{D \sin \phi}{D' - D \cos \phi}$.

If $D = D'$, or $S = S'$

$$B_0 = \frac{D}{\sin (\phi/2)}, \quad B'_0 = \frac{D}{\cos (\phi/2)},$$

$$\tan y' = \frac{\sin \phi}{\sin (\phi/2)} = \cos (\phi/2) / \sin (\phi/2)$$

Thus if $\phi = 0$, $\tan y' = \infty$, $y' = 90^\circ$, or the fringes are horizontal and $B = 2S$. If y' is nearly zero $\tan y' = \phi/(\phi^2/2) = 2/\phi$, changing very rapidly with ϕ .

If one grating of a pair, with identical grating spaces D , is moved parallel to itself, in front of the other, the effect to an eye at a finite distance is to make the grating spaces D virtually unequal; or

$$B = B_0 \frac{\sqrt{1 + (D'/D)^2 + 2(D'/D) \cos \phi}}{2 \cos (\phi/2)},$$

so that for an acute angle ϕ , the fringe breadth is increased. Thus B_0 is a minimum in case of coincident gratings.

The analogy is thus curiously as follows: The fringes just treated rotate with the rotation of either grating in its own plane and pass through a minimum size with fore and aft motion; whereas in the above results, the optical grating showed a passage through a maximum of size with the rotation of either grating in its own plane and a rotation of fringes with fore and aft motion of the grating. It is in terms of this analogy that an explanation of the optical interferences will have to be attempted, but there are some other complications

and the details are not yet clear in my mind. Thus in fig. 12, if G' is oblique at an angle ϕ , as at g' , path excess on the right in the case g_2' becomes path deficiency in case g_1' . Hence also a rotation, ϕ , of the grating around a vertical axis has the same effect as a fore and aft motion along the normal axis.

Returning to fig. 12 and the positions G_1' or G_2' of the grating, there is clearly path difference not only virtually for the rays distributed in the vertical plane, but also for those distributed in the horizontal plane, because the pencils (b, b' ; c, c') are separated and in case of a wide slit and oblique incidence reach the focal plane or lens or mirror obliquely. The result must therefore, in case of a wide slit, be a set of fringes due to pencils of parallel rays obliquely to the grating. The central region a of the grating G' is found on inspection to be yellow in the position G' , red in the position G_1' , and green in the position G_2' .

From this point of view the vertical fringes for the cases bb' or cc' are Fresnellian interferences, superimposed on whatever phase difference arrives at these points. If c is the effective width at the concave grating it may be shown that for $c = 1.6$ cm., $\lambda = 6 \times 10^{-5}$ cm., $d\theta = 3.7 \times 10^{-5}$, or about $6''$ of arc.

The corresponding deviation $d\theta_D$ equivalent to $d\lambda_D$ of the D_1D_2 lines would be (if the grating space is $D = 173 \times 10^{-6}$ cm. $\theta = 20^\circ$, nearly the normal deviations for yellow light),

$$d\theta_D = 3.7 \times 10^{-4}.$$

Thus

$$\frac{d\theta}{d\theta_D} = .1,$$

or, in this special case, there would be ten hair lines to the D_1D_2 space. As c is smaller or larger, there would be more or less lines. This is about the actual state of the case as observed. Finally if c is very small, the fringes are large.

To resume the evidence thus far obtained we may therefore assert that in the case of homogeneous light and a wide slit, or the absence of a slit, the field would either be bright or dark, as a whole. There is a single enormous horizontal fringe in the field. Hence the pronounced flickering with half wave length displacements of any part of the apparatus. With the slit narrowed until the Fraunhofer lines are seen sharply, the linear phenomenon in question appears. This may become ladder-like; but it always remains very narrow ($1/3 \times D_1D_2$) when the rulings of the two gratings are not quite parallel.

Furthermore the linear phenomena sometimes shows a behavior that suggests probable relations to the Fresnellian interferences, produced however not within the telescope (for

the interferences are seen together with the Fraunhofer lines in the principal focal plane), but outside of it, at the grating, as suggested by fig. 12. If the concave grating G' is screened off, until a width of strip parallel to the rulings and not more than five millimeters wide is used, the linear phenomena is much enhanced, being both broader and stronger, without losing its general character. Here the D lines are still visible. The ladder-like patterns show an equally pronounced coarsening.

It is thus obvious that diffraction and the resolving power of the grating must be in question, seeing that the total number of rulings has been greatly reduced. The use of screens with narrower slits carries the process further; but after the opening is less than two millimeters in width the available light is insufficient for further observation. If a small lens is used, the phenomena can still be seen over 3 meters beyond the principal focus of the grating.

A screen was now made as in fig. 14 *a*, with two slits about two millimeters wide and two millimeters apart (*b*) and placed over the effective part of the grating. The result after careful trial as to position was noteworthy. Oblique fringes were widened to many times the $D_1 D_2$ space and coarsened, showing a definite grid-like design, as in fig. 14 *b*, whereas on removing the screen, the original pattern of a regular succession of brilliant dots, fig. 14 *c*, again appeared.

It was with the linear fringes, however, that the evidence obtained was most striking; for these now showed the regular Fresnellian interference design, fig. 14 *d*. On removing the screen, the brilliant linear phenomenon, fig. 14 *e*, which in all the experiments made had thus far resisted manifolding, appeared at once. The pattern, moreover, when viewed with a smaller lens, within a meter in the direction of the rays, showed very definite enlargement, with distance. Though a fine slit was needed, the resolving power of the grating was now too small to show any Fraunhofer lines. Similar diffractions were obtained for a wire one millimeter or two millimeters in diameter. With the screen, fig. 14 *a*, and a bar, *b*, one millimeter wide, the fine interference grid due to the bar, and the coarse grid due to the spaces (the fine lines being about twice as narrow as the coarse but all of the same inclination) were often obtained together, fig. 14 *f*. A space 1^{cm} wide intersected by a bar three millimeters wide gave similar results, fine grids or thick lines, according as one or both spaces were used. If either mirror, M or N , is screened the whole phenomenon vanishes.

It follows then, that if rv and $v'r'$, fig. 15, represent the traces of the planes of the two reversed, overlapping spectra at the grating, b the focus and $aa'b$ the direction of the homo-

geneous diffracted rays condensed at b , that about $\cdot 5^{\text{cm}}$ of spectrum, $d'a'$ and ad' on either side of a , is chiefly active in modifying the resulting diffraction pattern. Within this, the homogeneous rays, cc' and dd' , are capable of interference. Although the wave fronts entering b are slightly spherical, their radius is about $r = 1$ meter and they may therefore be regarded plane. In such a case the angular width $d\alpha$ of the illuminated strip at b , for a width of screen $dd' = 1^{\text{cm}}$, between two extinctions, may be written

$$d\theta = \frac{d\alpha}{r} = \frac{\lambda}{dd'} = \frac{60 \times 10^{-6}}{1} = 6 \times 10^{-6}$$

whereas the angular breadth of the $D_1 D_2$ doublets is about 37×10^{-5} ; i. e., the rays from d and d' , if in phase, should cease to illuminate b at a breadth of about $1/6$ the distance between the sodium lines. The rays within dd' would correspond to greater widths; those from cc' , for instance, $\cdot 5$ millimeters apart, would illuminate twice the estimated width, so that as trip at b , with a breadth of one-third the interval $D_1 D_2$, is a reasonable average. All rays, however, would produce illumination at b . As the screens are narrower, not only would the fringe be broader, but more lines would appear because there is less overlapping. All this is in accord with observation.

With regard to waves of slightly different lengths, focussed at b' , each is there superposed on a wave of *different* length from its own and appreciable interference ceases for this reason. If the slit is widened the phenomenon (with white light) also vanishes by overlapping. The case of the screen with two spaces has already been treated in relation to fig. 12 and corresponds to the diffraction of a rod.

This seems to be an approach to the real nature of the phenomenon, though it does not give an adequate theory for it. The actual difference of wave length within which interference can take place, is naturally within the spectrum breadth of the diffraction pattern, $\delta\lambda = 2 \times 10^{-8}$ cm. observed, or within about 5×10^{-9} cm.

To return finally to the original inference, it appears that beating wave trains have not been observed, but that the striking scintillations are due to an exceptional susceptibility of the apparatus to laboratory tremors, when exhibiting the phenomenon in question. What has certainly been observed is the interference of a D_1 or D_2 line with a reversed D_1' or D_2' line, both having the same source and longitudinal axis. One can only assert, therefore, that light of the wave length interval of the breadth of these lines is capable of interference, when the line is reversed. The phenomena, as a whole, are diffractions of symmetrical *half wave fronts*, each of which may be separately controlled by the corresponding micrometers.

ART. XXXI.—*The Stratigraphic Position of the Hillsboro Sandstone**; by CHARLES S. PROSSER.

Historical Review†
Sections on Quaker Hill.
Sections near Hillsboro.
Sections near Turkey.

HISTORICAL REVIEW.

THE Hillsboro sandstone was named and described by Dr. Orton in 1871,† who stated that "As a typical example of it occurs so near Hillsboro [top of Lilley's Hill], it may be appropriately designated the Hillsboro sandstone."‡ Dr. Orton called this sandstone the upper and "6th member of the Niagara series in southwestern Ohio," and described the outcrops on Lilley's Hill as "a very fine-grained, purely silicious sandstone, about 30 feet thick, [which] directly overlies the Pentamerus beds at this point. The color of the rock varies from white to yellowish or brown, a small but varying proportion of iron seeming to account for the changes. There is a peculiar glistening appearance to the sandstone which makes it impossible to confound it with any other formation found in this part of the State."§

"The Geology of Highland County," by Dr. Orton, contains the following account of this sandstone:

"At Hillsboro, and on the eastern border of the county generally, a silicious sandstone of a good degree of purity is found terminating the [Niagara] series. Its composition is shown in the following analyses by Dr. Wormley:

Silica	94.10
Iron and alumina	3.60
Lime-carbonate	1.30
Magnesia-carbonate	0.39

The thickness of this sandstone in Lilley's Hill is 30 feet, and no greater thickness has been elsewhere observed. The sand that makes up the rock is fine-grained and but slightly cemented, crumbling easily from exposure to the weather or from mechanical abrasion. In color, it varies from white to deep yellow. There is always a glistening appearance about it which is a distinguishing characteristic of the rock. No fossils but a poorly

* Published by permission of the State Geologist of Ohio. Read before Section E of the American Association for the Advancement of Science at Columbus, Ohio, on December 28, 1915.

† Geological Survey of Ohio. Report of Progress in 1870, pp. 271, 283-285, 301, 306, 307, 309, and figs. 1, 3, 4, 5 and 6.

‡ Idem, p. 306.

§ Idem, p. 306.

preserved Halysites or chain-coral, have been discovered in the sandstone. The section at Lilley's Hill shows it in its proper place as crowning the Niagara series, but as it is not covered here by any later formation, the section is not as definite and satisfactory as the section of Grady's Hill, or better still, of the Burying Ground Hill, near Samantha. In the first of these instances, the sandstone is interstratified with the Pentamerus and Megalomus beds. In the second, it is directly overlain by 15 feet of Helderberg [Monroe] limestone, proved to be so by its most characteristic fossil.*

Dr. Orton in his description of "The Geological Scale of Ohio" in 1888 apparently was not absolutely certain that all of the Hillsboro sandstone belonged in the Niagara series, as may be seen from the following quotation:

"The Hillsboro sandstone is the last element in the Niagara group. It is found in but few localities, and its reference to the Niagara series in its entirety is not beyond question. In Highland county it has a thickness of thirty feet in several sections. It is composed of very pure, even-grained, sharp silicious sand. . . . The Hillsboro sandstone is sometimes built up above all the beds of the upper Niagara limestone, but again, it is, at times, interstratified with the beds of the Guelph division. In the latter case it is itself fossiliferous, but when found alone it seems destitute of all traces of life. These sandstones in the limestone formations [Niagara and Monroe] suggest in their peculiarities a common origin."†

The same description was repeated by Dr. Orton in 1890‡ and in 1893 in the last account which he published of the "Geological Scale and Geological Structure of Ohio."§

In 1911 Dr. E. O. Ulrich in the correlation table of the "Neopaleozoic—Silurian and Devonian" in his "Revision of the Paleozoic Systems," gave the Hillsboro sandstone as the basal formation of the Upper Cayugan and equivalent in age to the Sylvania sandstone in the Monroe formation of north-western Ohio.¶ The writer has found no reference to this formation in the text of Dr. Ulrich's monograph, and does not know the basis for this change in the age of the Hillsboro sandstone.

Later it appears in the same stratigraphic position in Dr. Bassler's "Silurian Correlation Table" in his "Bibliographic Index of American Ordovician and Silurian Fossils."¶¶ In this table, however, the Sylvania sandstone and the greater part of

* Idem, p. 283.

† Report Geological Survey of Ohio, vol. vi, pp. 14, 15.

‡ Idem, 3d Organization, 1st Annual Report, p. 20.

§ Idem, vol. vii, pp. 12, 13.

¶ Bull. Geol. Soc., America, vol. xxii, September, 1911, pl. 28.

¶¶ U. S. Nat. Mus., Bull. 92, vol. ii, November, 1915, pl. 3.

the Monroe has been raised from the Cayugan series to the Helderbergian of the Devonian.

SECTIONS ON QUAKER HILL.

It will be recalled that Dr. Orton gave the section on the Burying Ground Hill (Quaker Hill, which is also said to be called High Top), about a mile southwest of Samantha, Highland County. In July, 1915, the road down the southern side of the hill to the farm house of Mr. S. B. Benigar had been freshly graded and the gutters cleaned out so that the rocks were more clearly shown than at any other time when it has been visited by the writer. A section was measured at this time with the assistance of Mr. Kenneth C. Cottingham, which is believed to give the stratigraphic position more accurately than in any other account which is known to the writer. The section begins on top of the hill near the western side of the Cemetery and follows the road south down the hill to the house of Mr. S. B. Benigar.

Section along the highway on the southern side of Quaker Hill.

No.	Thickness		Total Thickness	
	Ft.	In.	Ft.	In.
15. <i>Ohio shale</i> .—Specimens of black shale out of hole for telephone pole on highway near the Cemetery. Covered interval for some distance down the highway ..	17	8	75	1
14. Black, fissile shale weathering to a brownish color. Exposed by roadside below the James Burns house	4	0	57	5
13. Covered interval	2	0	53	5
12. <i>Monroe formation</i> .—Brownish to grayish magnesian limestone which is not continuously exposed, since the interval is partly covered. A few fossils were found	12	0	51	5
11. Covered interval	1	0	39	5
10. <i>Hillsboro sandstone</i> .—White, fine-grained sandstone, which crushes into a fine sand and weathers on the surface to a brown or rusty color. No effervescence in cold HCl	2	5	38	5
9. Covered interval in road gutter	4	6	36	0
8. Light gray to brownish, porous rock which effervesces in cold HCl, and has a slight bituminous odor	9	0	31	6

No.	Thickness		Total Thickness	
	Ft.	In.	Ft.	In.
7. Light gray, rather porous limestone which effervesces strongly in HCl	11	0	30	9
6. Partly covered interval; but showing some thin-bedded layers and others which are rather thicker with coarser texture and brownish color. The lowest layer has a rather strong effervescence in cold HCl	6	1	29	10
5. Light gray to whitish, quartz sandstone with no effervescence in cold HCl. This sandstone is apparently bedded in the gutter and is the lowest one exposed on the highway. The thickness of the interval from the top of the highest sandstone to the base of the lowest one is 16 feet 8 inches	2	0	23	9
4. Thinner bedded limestone, mottled light to dark gray color, bituminous odor, fairly strong effervescence in cold HCl, and lithologically somewhat similar to the Monroe	2	11	21	9
3. <i>Cedarville dolomite</i> .—Buff as weathered, rather porous rock, with scarcely any effervescence in cold HCl, which lithologically is like the Cedarville	5	8	18	10
2. Ledge of rock on road which is obviously Cedarville; but most of the interval is covered	9	2	13	2
1. Gray, glistening dolomite which is very porous, containing holes of some size and is also bituminous. A few specimens of <i>Trimerella</i> were found. At the time this section was studied in 1915, four feet of this zone was shown in the eastern wall of the cellar that was being dug for a house on the S. B. Benigar farm	4	0	4	0

Under the lowest layer of sandstone on the western side of the highway is a 17-inch band of black rather gritty shale, and still higher, between the lower sandstone and the porous limestone of zone No. 7, black shale also occurs. This black shale was noted by Dr. Orton, for he stated "that the sandstone frequently contains thin seams of slate, not to be distinguished in any way by its appearance from the great deposit that is shown in such force in the Eastern hills of the County [High-

land] . . . The Samantha Hill [Quaker Hill] also shows them in small extent. . . .

The occurrence of sandstone and black slate in the Niagara series marks the beginning of a great change in the condition of the seas that prevailed here." * The lower shale zone appears more nearly in place than those above and perhaps they were deposited with the limestone. The writer is not certain that the above explanation is correct and perhaps the black shale has only slumped down the hill, for some was seen still lower in the soil just above the Cedarville dolomite, as shown in the rock wall of Benigar's cellar.

To the east of the highway is the Charles Rogers farm, and in the first gully about opposite the sandstone outcrops in the road gutter, two layers of sandstone are exposed as shown in the following section :

Section in gully on the Charles Rogers farm.

No.		Thickness		Total	
		Ft.	In.	Ft.	In.
4.	<i>Hillsboro sandstone.</i> —Light colored sandstone composed of fine grains of quartz sand. Blocks with a thickness of at least 2 feet 2 inches as shown in small excavation east of old deserted house.	2	2	16	10
3.	Covered interval -----	11	1	14	8
2.	Layer of quartz sandstone outcropping in gully and on bank to the east, with a thickness of at least 10 inches -----		10	3	7
1.	Gray magnesian limestone, the top of which is apparently rather sandy ----	2	9	2	9

The covered interval of 11 feet 1 inch between the two sandstone layers in the above section agrees closely in thickness with that of the interval between the two sandstones on the road (Nos. 5 and 10) which is 12 feet 3 inches.

On the knoll to the east of this gully are fairly large blocks of the Hillsboro sandstone which are apparently from a broken down ledge. From the top to the bottom of these sandstone blocks on the knoll is 7 feet 8 inches ; but the thickest individual block is 2 feet 2 inches. In another gully just to the east of the knoll, it is 3 feet 1 inch from the base to the top of the sandstone blocks, or 6 feet 3 inches from the base in the gully to the top of the highest sandstone block on the knoll.

This section may be represented as follows :

* Geol. Surv. Ohio Report of Progress in 1870, pp. 283, 284.

Section on knoll and in gully on the Charles Rogers farm.

No.	Thickness		Total Thickness	
	Ft.	In.	Ft.	In.
4. <i>Hillsboro sandstone</i> .—Large blocks of very light gray to white, fine-grained, quartz sandstone. From top to base of sandstone blocks	7	8	20	11
3. Covered interval of 2 feet 1 inch on knoll ; but limestone ledge exposed in gully just to the east with interval of 2 feet 5 inches between the lowest sandstone block in the upper part of the gully and the lower sandstone layer	2	5	13	3
2. Sandstone layer which is apparently in place	1	3	10	10
1. Magnesian limestone which effervesces slowly in cold HCl. The rock is hard except where weathered and in lithologic appearance it resembles the Monroe more than the Cedarville. The ledge is rather blocky and rough, more like the thick-bedded Monroe, and does not contain the pores and cavities which are so generally found in the Cedarville dolomite. No fossils were found	9	7	9	7

The sandstone is apparently dipping to the west as shown by the elevation of the highest outcrops. The top of the sandstone layer in the gully as leveled is 1 foot lower than the top of the sandstone block on the knoll to the east, or 5 feet by the barometer ; while the top of the highest layer of sandstone in the road gutter is 5 feet lower according to the barometer than the top of the upper sandstone layer in the gully to the east.

In the field to the west of the road on land owned by Mrs. Ellen Burns are outcrops of rocks and three small quarries in the limestone have been worked to some extent. The following section was made in this field :

Section on the Mrs. Ellen Burns farm.

No.	Thickness		Total Thickness	
	Ft.	In.	Ft.	In.
7. <i>Ohio shale</i> .—Base of black shale outcrop on the road.				
6. Covered interval. As leveled by Mr. Walter A. Verwiebe from the top of the limestone in the third quarry to the				

No.		Thickness		Total Thickness	
		Ft.	In.	Ft.	In.
	base of the outcrop of the Ohio shale on the road is 4 feet 10 inches. From the top of the same limestone to outcrops of Ohio shale in gullies to the northwest is 10 feet by the barometer. On the surface above the top of this quarry are loose blocks of white, fine-grained, quartz sandstone, similar lithologically to the upper layer of sandstone in the road gutter.	4	10	35	2
5.	<i>Monroe dolomite</i> .—Compact, light to bluish-gray, hard rock, which is somewhat porous, and contains some fossils. The upper part of this zone is shown in the highest or third quarry.	8	10	30	4
4.	Rather massive layer, somewhat granular, rather porous and effervescence fairly strong in cold commercial HCl. This layer forms the top of the middle or second quarry and is rather similar lithologically to the porous 11-inch stratum (No. 7) in the road gutter.	2	6	21	6
3.	Drab or brownish to gray rock weathering to a very light gray which is fairly compact, lithologically like the Monroe dolomite, and contains a few fossils. In the floor of the quarry are irregular dome-like elevations similar to masses that are not infrequently found in the Monroe. The rock has been quarried and crushed to some extent for highways.	6	6	19	0
2.	Covered interval.	5	5	12	6
1.	<i>Cedarville dolomite</i> .—Porous, buff to gray rock which effervesces strongly in cold commercial HCl. At the bottom of this lowest or third quarry is a heavy layer, and this zone has the lithologic appearance of the Cedarville; although perhaps not all of the upper part of this quarry belongs in the Cedarville. No fossils were found.	7	1	7	1

Across the gully to the east of the middle quarry in the above section are loose blocks of light gray, quartz sandstone which are evidently from a broken-down stratum of the Hillsboro sandstone. These loose sandstone blocks occur in a vertical interval of 6 feet and the lowest ones, as leveled across the

gully, lie a little lower than opposite the base of the massive layer (No. 4) at the top of the quarry. The top of the massive layer (No. 4) at the top of the middle quarry, according to one reading of the barometer is 5 feet, and as leveled by Mr. Cottingham 6 feet, lower than the top of the 11-inch porous layer (No. 7) of the road section, which it resembles lithologically. The 9-inch brownish, porous limestone (No. 8) of the road section, perhaps might be united with the underlying 11-inch layer, and then above this limestone zone is a covered interval (No. 9) of 4 feet 6 inches before the base of the exposed upper layer of Hillsboro sandstone (No. 10) is reached. It is very possible that more or less of this covered interval may belong in the sandstone zone. At least it appears probable that the zone of loose blocks of sandstone to the west of the highway represent the continuation of this upper zone of the Hillsboro sandstone, and stratigraphically below it is the middle quarry of limestone containing Monroe fossils.

The fossils collected in the Monroe dolomite of Quaker Hill have been studied and identified by Miss Rose Gormley, who is making a thorough study of the entire Monroe fauna of Ohio, and are concurred in by the writer. On the highway in No. 12 of that section, which is above the Hillsboro sandstone, the following species were found:

1. *Hindella?* (*Greenfieldia*) *whitfieldi* Grabau. This species was identified by Whitfield as *Meristella bella** and is reported by Grabau as "Common in the Greenfield dolomite at Greenfield, Ohio." †

2. *Hindella?* (*Greenfieldia?*) *rotundata* (Whitfield) Grabau. This is apparently the species that was identified by Whitfield as *Nucleospira rotundata* from Greenfield, Ohio, and is listed by Bassler as *Whitfieldella rotundata*.‡ Grabau states that "The species described by Whitfield occurs in the Greenfield dolomite of Greenfield, Ohio, where it has been obtained as external and internal molds, often indistinguishable from the internal molds of *Hindella (?) whitfieldi*, the originals from which Whitfield's descriptions were made have not been seen, and none of the specimens from Greenfield, Ohio, in the collection of Columbia University show the characters of this species." § The specimens are all in the form of external or internal impressions in which condition it is difficult to separate the two species; but part of the specimens are ventricose with strongly incurved beaks, which are the most important distinguishing characters given for this species.

* Ann. N. Y. Acad. Sci., vol. v, p. 510, pl. V, figs. 8-10, 1891; and Report Geol. Surv. Ohio, vol. vii, p. 412, pl. I, figs. 8-10, 1893.

† Michigan Geol. and Biol. Survey, Pub. 2, Geol. Ser. 1, p. 149, 1910.

‡ U. S. National Museum, Bull. 92, vol. ii, p. 1330, 1915.

§ Michigan Geol. and Biol. Survey, Pub. 2, Geol. Ser., 1, p. 151, 1910.

3. *Leperditia ohioensis* Bassler. This is the species which Whitfield identified as *L. alta* from Bellevue, Sandusky County, Ohio, and Grabau in 1910 renamed *L. altoides*, and gave for additional distribution the "Greenfield dolomite of Greenfield and Ballville, Ohio."* The name of *L. altoides*, however, was given by Weller in 1903 to a species in the Decker Ferry formation of New Jersey† and on account of this preoccupation Bassler has renamed the Ohio specimens *L. ohioensis*.‡

In the field on the Mrs. Ellen Burns farm, in No. 5 of that section, a few rods to the west of the road, and apparently stratigraphically above the Hillsboro sandstone, the following species were collected:

1. *Hindella*? (*Greenfieldia*?) *rotundata* (Whitfield) Grabau.

2. *Rhynchospira præformosa* Grabau.

These specimens are apparently identical with those from Greenfield, Ohio, which Whitfield identified as *Retzia formosa*, the species that Hall used as the type for his genus *Rhynchospira*. One of the specimens described by Whitfield is in the Geological Museum of Ohio State University, and it is true that it is smaller than the adult forms of *Rhynchospira formosa* Hall; but among the specimens from Quaker Hill are larger ones which it is difficult to separate from medium-sized specimens of *R. formosa*. The type specimens of *Rhynchospira formosa* Hall are from the New Scotland formation of the Helderbergian series in the Helderberg Mountains of Albany County, New York. The species has, however, been identified by Maynard in the Keyser member of the Helderberg formation in Maryland and West Virginia,§ which is the oldest member of the Helderberg formation of those states, underlying the Coeymans member or limestone. Still earlier the species had been identified by Weller in the Decker Ferry formation of New Jersey,|| which he believed was the southern extension of the Coralline limestone of New York that belongs in the Cayugan series, and has been renamed the Cobleskill limestone. Dr. Swartz of the Maryland Survey, however, correlates the Decker Ferry formation with the lower or *Chonetes jerseyensis* zone of the Keyser member,¶ and this latter correlation is apparently accepted by Bassler.**

* Idem, p. 205.

† Geol. Surv. New Jersey. Report on Paleontology, vol. iii, pp. 63, 252, pl. XXIII, figs. 1, 2.

‡ U. S. National Museum, Bull. 92, vol. 1, p. 704, 1915.

§ Maryland Geol. Survey, Lower Devonian, p. 426, 1913.

|| Geol. Survey of New Jersey. Report on Paleontology, vol. iii, p. 240, 1903.

¶ Maryland Geol. Survey, Lower Devonian, p. 98, 1913.

** U. S. National Museum, Bull. 92, vol. ii, 1915, pl. 3—Silurian Correlation Table.

3. *Leperditia ohioensis* Bassler.

The four species listed above from the Monroe limestone overlying the Hillsboro sandstone on the southern slope of Quaker Hill all occur in the Greenfield dolomite at Greenfield. The three species of brachiopods were all reported by Whitfield from the hydraulic limestone or waterlime beds of the Lower Helderberg group [Greenfield dolomite] of Greenfield, Ohio, and Grabau in his monograph on the Monroe formation has not increased the range or localities of these species. The *Leperditia ohioensis* is given by Grabau as occurring in the Greenfield dolomite both at Greenfield and Ballville, Ohio, and in addition in the lower Monroe formation of Bellevue, Ohio. So far as the evidence of these fossils goes it shows that the limestone overlying the Hillsboro sandstone on Quaker Hill may be correlated with the Greenfield dolomite of Greenfield.

A few fossils were also found in the middle quarry on the Mrs. Ellen Burns farm, which is apparently stratigraphically below the upper zone of the Hillsboro sandstone. The two following species were collected in this quarry:

1. *Hindella?* (*Greenfieldia?*) *rotundata* (Whitfield) Grabau.
2. *Leperditia ohioensis* Bassler.

The specimens of *Leperditia* are the more abundant and both of the above species occur in the Greenfield dolomite, as has already been stated. It is also to be noted that both species, so far as known, are restricted to the Monroe formation, and this together with the lithologic appearance of the rock seems to prove conclusively that the upper zone of the Hillsboro sandstone on Quaker Hill occurs in the Monroe formation in the Cayuga series instead of at the top of the Niagaran series.

In the highway section is a lower zone of sandstone (No. 5), the top of which is 12½ feet below the lowest exposure of the upper sandstone stratum (No. 10). All of this intervening rock has the lithologic appearance of the Monroe and although fossils were not found in the exposures along the highway, still it is believed to belong in the Monroe. Also below the lower sandstone stratum is a zone of thin-bedded limestone, 2 feet 11 inches thick, which lithologically is fairly similar to the Monroe; before the buff, porous rock is reached which is considered as belonging in the Cedarville dolomite. Fossils were not found in the upper two zones (Nos. 2 and 3) of the Cedarville, which have a thickness of 14 feet 10 inches; but about two-thirds of this interval is covered and the opportunity for hunting fossils along the road is not good. In the next lower zone (No. 1), 4 feet of which was shown in the excavation for

the Benigar house, specimens of *Trimerella* (a genus that according to Schuchert is confined to the Guelph and Niagara of the United States and Canada and the Upper Silurian of the Baltic region in Europe) were found, and the lithologic appearance of the rock is that of the typical Cedarville dolomite, so that apparently there is no question as to this rock belonging in that formation.

SECTIONS NEAR HILLSBORO.

It is, of course, possible that the sandstones described by Dr. Orton at several localities in Highland County may occur at more than one horizon. This apparently is true if Dr. Orton's statement is correct that "the sandstone is interstratified with the *Pentamerus* and *Megalomus* beds"* in the Grady's Hill section, four miles north of Hillsboro. The outcrops along the pike from Hillsboro to Samantha were carefully examined, and rock with the lithologic characters of the Cedarville dolomite was found to within 15 feet of the top of the hill at the four corners near the house of Charles F. Chaplin. Mr. Chaplin stated that he had never seen sandstone on his farm, and the nearest outcrop he knew is on Lilley's Hill, to the east of Hillsboro.

The top of Lilley's Hill, about one mile east of the Parker Hotel in Hillsboro, is the locality from which Dr. Orton named the sandstone. The pike from Hillsboro to Marshall crosses this hill and gives the best outcrops to be found on it; but they are not continuous and the sandstone occurs in loose blocks, apparently from a broken down ledge.

Section of upper part of Lilley's Hill.

No.	Thickness	Total	Thickness	Total
	Ft.	In.	Ft.	In.
3. Top of hill in field above highway. Covered. Seven feet as leveled by Mr. Wendell Z. Miller	7	0	31	6
2. <i>Hillsboro sandstone</i> .—Loose blocks of fairly massive, light gray to brownish-gray, friable, quartz sandstone, near the summit of the hill, on the northern side of the highway, opposite the house of Lea Williams. Lower part of zone mostly covered. Ten feet according to the barometer, and 9½ feet as leveled by Mr. Miller	9	6	24	6

* Geol. Survey Ohio, Report Progress in 1870, 1871, p. 283.

No.	Thickness		Total Thickness	
	Ft.	In.	Ft.	In.
1. <i>Cedarville dolomite</i> .—Light gray to buff, porous rock, part of which contains numerous large specimens of <i>Pentamerus oblongus</i> Sowb. Fifteen feet exposed according to the barometer ----	15	0	15	0

Dr. Orton stated that the sandstone is shown at this locality "in its proper place as crowning the Niagara series,"* with a thickness of 30 feet. It appears at present impossible to say whether all the summit of the hill above the top of the exposed Cedarville dolomite (No. 1) is sandstone or not. If it is, however, then as leveled by Mr. Miller it is only $16\frac{1}{2}$ feet from the top of the outcropping Cedarville dolomite containing numerous specimens of *Pentamerus oblongus* Sowb., to the summit of the hill.

SECTIONS NEAR TURKEY.

Dr. Orton stated that "other localities at which it [Hillsboro sandstone] occurs are principally to be found at the foot of the slate hills on the eastern side of the county. The following named points give good exposures: The Marshall and Sinking Spring road near the house of John Bell, Esq.; the farm of Hon. J. L. Hughes; the foot of Stult's Mountain; the Caves of Rocky Fork."† All of these localities, with the exception of the Hughes farm, were located, and the outcrops on and near the farm formerly owned by John Bell, now owned by D. E. Stewart, were found to be the best. This locality is about 5 miles southeast of Marshall and 1 mile southeast of Turkey on the pike from Marshall to Sinking Spring, and 3 miles northwest of the last-named place, in Brush Creek Township. At the first four corners southeast of Turkey is the house of A. L. Rhoads, and on the eastern side of the north and south road on the Stewart farm, a short distance south of the Rhoads house, is a small quarry in the so-called "marl" of this region, which has been worked for the highway. In this quarry is a sandstone which is lithologically like the Sylvania sandstone; but apparently does not extend entirely across the quarry. The following section of this outcrop was made:

Section on the D. E. Stewart farm.

No.	Thickness Feet	Total Thickness Feet
3. Drab limestone lithologically like the Monroe and rather harder than the lowest zone in the quarry. No fossils were seen -----	5 ±	9 ±

* *Idem*, p. 283.† *Idem*, p. 283.

No.	Thickness Feet	Total Thickness Feet
2. <i>Hillsboro sandstone</i> .—Light to darkish gray, very friable sandstone composed of grains of quartz sand	1 ±	4 ±
1. Drab, porous limestone ; but no fossils were seen	3 ±	3 ±

On the other side of the north and south road in the field, a few rods below the house of Mr. Rhoads, is the thickest ledge of the Hillsboro sandstone that was found in this region.

Section on the A. L. Rhoads farm.

No.	Thickness Ft. In.		Total Thickness Ft. In.	
3. <i>Hillsboro sandstone</i> .—Dark gray sandstone composed of quartz grains and much of it is friable although some of it is harder	3	2	6	8
2. Perhaps covered interval		6 ±	3	6
1. The so-called "marl" which is a drab, rather soft limestone that crumbles on weathering	3	0	3	0

On the pike just northeast of the A. L. Rhoads' house, and by the barometer 5 feet lower than the quarry on the Stewart farm, is an outcrop of about 8 feet of black, bituminous shale, which evidently is the Ohio shale.

Another outcrop of the sandstone is shown on the north and south road a few rods north of the four-corners and house of Mr. A. L. Rhoads, where the following section was measured :

Section on road north of Mr. A. L. Rhoads' house.

No.	Thickness Feet	Total Thickness Feet
3. <i>Hillsboro sandstone</i> .—Dark gray, friable sandstone composed of grains of quartz sand	1½±	18
2. The so-called “marl” which is used for highways. Drab colored, rather granular limestone in which no fossils were found, that is supposed to be Monroe	14 +	16½
1. Massive drab-colored limestone at base of road section, which contains <i>Favosites</i> , and possibly belongs in the Cedarville dolomite	2½	2½

On the A. L. Rhoads' farm to the west of the north and south road is a ledge of dark gray, friable sandstone composed of grains of quartz sand, with a thickness of $1\frac{1}{2}$ feet.

The sandstone is also shown on the northern side of the Marshall-Sinking Spring Pike, northwest of the house of Mr. D. E. Stewart, which is the one formerly occupied by Mr. John Bell.

Section on Pike northeast of the D. E. Stewart house.

No.	Thickness		Total	
	Ft.	In.	Ft.	In.
3. <i>Hillsboro sandstone</i> .—A ledge by the side of the highway, which is more or less broken down, of light to dark colored, friable sandstone, composed of grains of quartz sand. Mr. Stewart stated that this sandstone caps most of the knolls in this locality -----	2	10	15	10
2. Covered interval -----	10	0	13	0
1. The so-called "marl," drab limestone which crumbles on weathering ----	3	0	3	0

It is not certain that all of these outcrops of sandstone near Turkey occur at the same stratigraphic position; but lack of time prevented the writer from carefully investigating this point. It is not improbable that they belong in two horizons similar to the outcrops already described on Quaker Hill.

Ohio State University,
Columbus, Ohio.

ART. XXXII.—*Bottom Control of Marine Faunas as Illustrated by Dredging in the Bay of Fundy*;* by E. M. KINDLE.

Introduction.

THE influence exercised by the physical character of bottom materials on the composition of the marine faunas living upon them, has appeared so evident to many paleontologists, that it is generally assumed or taken for granted by them. Others have held that the character of the bottom materials had little or no influence in determining the composition and distribution of the faunas to which they furnish a habitat. It is for various and obvious reasons much more difficult to secure conclusive evidence from fossil faunas and consolidated sediments for either opinion, than it is to obtain convincing evidence from a study of living marine faunas. An examination of the papers of zoologists who have enjoyed a large experience in collecting marine molluscs will show that, without exception, they recognize in the physical characteristics of the sea bottom materials a potent factor in determining the abundance and kind of bottom life. Concerning this point Dr. F. B. Sumner writes as follows:

“Foremost among the conditions determining the distribution of the bottom-dwelling organisms, we have found to be the character of the bottom considered chiefly in relation to its physical texture.”†

The dredging operations on which such conclusions as these rest, however, have seldom been undertaken for the purpose of estimating the influence and importance of this factor. The discovery and description of new species has generally been for the zoologist too absorbing a subject to permit him to give more than secondary consideration to problems involving the influence of environment on bottom life. It has seemed to the writer that collections of marine invertebrates which were made primarily for the purpose of ascertaining in a limited area the influence of bottom environment on the distribution and association of the forms of life met with, would be instructive alike to the zoologist and the paleontologist. Dredging for this purpose was undertaken by the writer during the summer of 1914 on the west coast of Nova Scotia. Mr. E. J. Whittaker assisted in this work. The dredging and collecting stations occupied were with one exception in the Minas Basin and Digby Bay. Their precise location, relation to low tide

* Published with permission of the Director of the Geological Survey of Canada.

† Bull. Bureau of Fish, U. S., vol. xxviii, p. 1229, 1908.

and the character of sediments represented are shown in the following list of stations:

Collecting Stations.

- Sta. No. 1. Digby, N. S. Intertidal zone, boulder strewn beach.
2. Digby, N. S. 300 to 400 yards east of Government pier in 2 fathoms. Soft black mud bottom.
3. Digby, N. S. 3 to 4 miles N.E. of Digby. Outer margin and inside of bar running S.W. from Bear Island; in 3 to 6 fathoms. Collection nearly all from muddy sand.
4. Bear Island, N.E. of Digby, N. S. 4 miles. Intertidal zone, boulder strewn beach.
5. Head of St. Mary's Bay, N. S. Intertidal zone. Beach of sand, gravel and mud.
6. Kingsport, N. S. $1\frac{1}{2}$ miles N.E. of pier. Gravel bottom, shallow water.
7. Kingsport, N. S. Channel opposite Kingsport pier; 1 fathom at low tide; sandy mud bottom.
8. Kingsport, N. S. Intertidal zone. Beach of rocks, gravel and muddy sand. (Living shells in pools.)
9. Kingsport, N. S. Beach of sand and mud between tides. (Dead shells.)
10. Mouth of Avon River, opposite Chiverie, Pt. N. S. 2 to 6 fathoms, rocky and sandy bottom.

The term intertidal zone is used here instead of littoral zone, which was formerly in universal use for the zone between low and high tide, because the latter term has in recent years been used by Dall,* Grabau† and some others to include the marine habitat down to depths of 100 fathoms.

The dredging stations selected are all in shallow water, the maximum depth being 6 or 7 fathoms at low tide. The locations are in each case near river mouths and subject to the strong tidal currents heavily charged with sediment which are characteristic of all the inlets and bays connected with the Bay of Fundy. In all the essential elements which go to make up the molluscan habitat at stations 2, 3, 6 and 10 there is very little perceptible difference save in one respect.‡ The phys-

* Deep Sea Molluscs and the conditions under which they exist. Proc. Biol. Soc. Washington, vol. v, p. 3, 1888-90.

† Principles of Stratigraphy, p. 646.

‡ Station 7 is omitted from the discussion following the list of species because it lies within the limits of the brackish water belt. The shells dredged there were with one or two exceptions dead shells and represent an aggregation due to tidal currents which there have their maximum strength in this mid channel in front of the mouth of Cornwallis River.

ical character of the bottom differs widely. At station 2 the bottom is very soft nearly black mud with a large content of organic matter. Stations 6 and 10 have hard bottoms, the materials being chiefly gravel in the case of station 6, and at station 10 gravel, angular pieces of rock and sand. The bottom of station 3 is allied to that of station 2, but much firmer and comprises a considerable amount of sand. It belongs to the muddy sand type of bottom. Since the different stations differ with respect to factors likely to affect molluscan life only in the character of the bottom, any very considerable differences in the molluscan assemblage which they may show must be ascribed to this as being the only varying factor present.* If the character of the bottom is an important factor in determining the composition of a fauna we should expect the assemblages from the stations with hard bottoms to have a large number of species in common, and the soft mud and hard bottom stations to have very few species in common. Inspection of the following table in which the occurrence of each species in the list is indicated for each station at which it was taken by a check, will indicate to what extent this is true.

Analysis of Table of Species.

I am indebted to Dr. Paul Bartsch, Curator of Marine Molluscs in the U. S. National Museum, for the determination of the shells listed on the following page.

This list of 51 species includes three gasteropods which do not appear to have been previously recognized in Canadian waters. These species are:

Ilyanassa obsoleta Say.

Melampus lineatus Say.

Tritia trivittata Say.

All of the other species in the list are recorded by Whiteaves from Eastern Canada.†

The table shows that stations 6 and 10 furnished each 18 species or a total of 22 species. Of the 22 species found at the two stations 13 are common to both stations. In the fauna of either station 72 per cent of the species are common to the fauna of the other station.

* The influence of decreasing salinity in reducing the abundance of marine life may be observed in ascending the estuaries of streams like the Avon. The discussion of this factor in faunal control is postponed for a future paper.

†Catalogue of the Marine Invertebrata of Eastern Canada, pp. 1-272, Can. Geol. Surv., 1901.

LIST OF MOLLUSCA.

[illegible]

Station 2 with a soft blackish mud bottom furnished 10 species of pelecypods and gasteropods. Only 2 of these or 21 per cent are common to the fauna of the stations with hard or rocky bottom. One of these two is the *Littorina litorea*, a species which has nearly universal distribution in the intertidal and very shallow water zone. Station 3 with a muddy, sandy bottom yielded 24 species. Only 5 of these 24, or 20 per cent of the fauna, are found at stations 6 and 10, which are typical hard bottom stations. The composition of the fauna of station 3 compared with that of station 2, however, reveals a very close relationship between the two. Nine of the 10 species or 90 per cent of station 2 are present in station 3. Thus we find that the likeness and differences between the faunas at the different stations are directly correlated with the resemblance or contrast shown by the types of bottom at these stations. Summing up these observations we find that in the case of two stations with hard bottom 72 per cent of the species of each station are common to the fauna of the other. A soft mud bottom shows a fauna with only 21 per cent of its species common to the fauna of the hard bottom station. This soft mud fauna compared with the fauna of a rather closely allied type of bottom composed of muddy sand shows 90 per cent of its species common to the fauna of the latter type of bottom. In other words the faunules from different stations in the same general region resemble each other in composition in approximately the same degree as do the bottom materials on which they live.

In the preceding comparison of faunules from different types of bottom only the gasteropods and pelecypods have been considered. If, however, we include in the comparison the total fauna as represented by both living and dead forms taken from each station the contrast in the case of unlike bottoms is even more striking than when only the two groups above mentioned are made the basis of the investigation. The total fauna collected at station 2, which has a soft black mud bottom, includes 14 species while station 10 with a hard bottom yielded 26 species including living and dead forms. Only three species or 7 per cent of the total fauna of the two stations are common to both stations. Since in this comparison both living and dead shells are included, it disposes of the contention of some geologists, that while the assemblage of living forms may be conditioned by the kind of bottom the mixing of the dead shells by current action destroys in the fossil fauna any distinctions between facies representing distinct types of bottom. It is true that in certain areas a limited amount of this post-mortem shifting of faunules may occur. But the dredge indicates that its relative importance in modifying the character

FIG. 1, A and B.

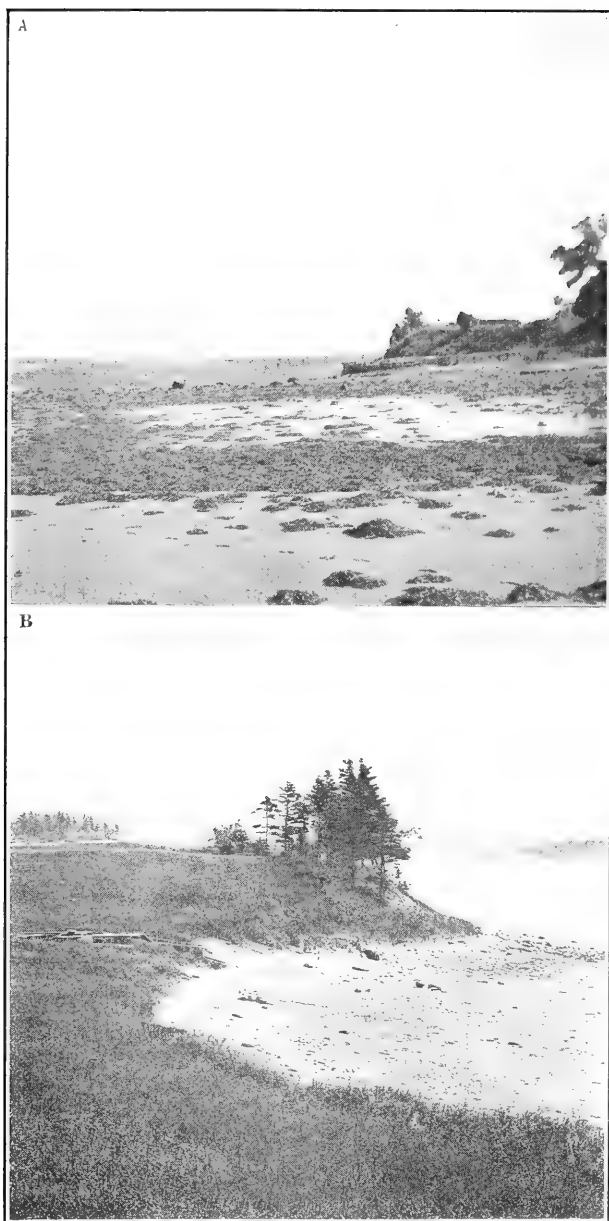


FIG. 1. A. Intertidal zone. Boulder, gravel and sand facies with rich molluscan fauna and sea-weed flora, Digby, N. S.

B. Intertidal zone. Shingle and small boulder facies with a rich gastropod fauna, Pictou Co., N. S. Photo by H. I. Smith.

of the fossil faunal facies as determined by bottom conditions is but little greater than the influence of the winds on land in mixing the products of plant life of swamp, upland and desert habitat.

The grouping of species on the intertidal zone of the Nova Scotia coast is not less instructive than that of the shallow water zone near shore. The fauna of the intertidal zone illustrates the same class of facts respecting the influence of the character of habitat on variety and number of marine invertebrates as the zone immediately below low tide. A comparatively small number of species live in this zone, but some of these are represented by enormous numbers of individuals where the conditions of life are favorable. *Balanus*, a genus not included in the lists given because it is a crustacean, is sometimes represented by thousands of individuals to the square yard. Its presence or absence is determined entirely by the physical character of the beach. The great vertical range of the tides on this coast, amounting to 40 feet or more at most points, gives an intertidal zone of far greater width and area than that found on most coasts. In considering the fauna of the intertidal zone station 5 will be omitted because it represents essentially a faunal aggregation due to wave action. The shells collected at this station are from the beach at the head of St. Mary's Bay where wave action is at times effective in bringing together molluscs derived from various types of habitat.

The beaches at Digby (fig. 1B) and the shore at Bear Island, four miles N. E. of Digby, furnish representative examples of the fauna of the intertidal zone of the Bay of Fundy. The shore of the island and the eastern part of the beach at Digby is strewn with glacial boulders of various sizes with gravel, sand and shingle between. Nine species were collected on the Digby beach and four on the Bear Island beach. While all of the latter were found on the Digby beach, it is interesting to note that only two of the 9 species comprising the Digby and Bear Island beach fauna were found in the black mud fauna of the bay which was dredged only a few hundred yards from the Digby beach. Although only a few species are present in this intertidal fauna at Digby and Bear Island, an enormous number of individuals represent some of these species. The boulders are often closely covered with small gasteropods. In many localities there are probably several hundred specimens of *Littorina litorea* to the square yard. Evidently this rocky beach affords a highly favorable molluscan environment where life is so abundant that every step on the beach destroys scores of shells.

FIG. 2, A and B.



FIG. 2. A. Intertidal zone. Grey mud facies, nearly barren of molluscan life.
B. Intertidal zone. Drifting sand facies, barren of molluscan life. Kingsport, N. S.

Fig. 3A shows the vertical face of an intertidal ledge with a deeply etched surface,—a type of surface which is apt to shelter the maximum amount of intertidal gasteropod life. Parts of the surface seen in the photograph show more than 100 gasteropods to the square foot.

Let us compare this stony beach at Digby as a habitat for invertebrate life with another type of beach which is very common about the Bay of Fundy. At the mouth of the Avon River an island about $3\frac{1}{2}$ miles in length and half a mile in width is exposed at low tide. This island, which is composed entirely of sand, is covered at high tide by from 10 to 25 feet of water. The strong tidal currents keep the surface of the sand constantly shifting during ebb and flow. The backward and forward drift of the sand makes it impossible for marine life to establish itself here. This type of drifting sand surface is shown in fig. 2B. I did not find a single living shell on the island and only 3 or 4 dead shells were seen. The surface appears to be as barren of life as a desert of sand in an arid climate would be. The striking contrast between this barren sandy beach and the rocky beach at Bear Island, where nearly every square yard is occupied by scores of shells, as a habitat for marine life is clearly due entirely to the different character of the materials comprising the two beaches. The barren character of this intertidal sand island also furnishes a striking contrast to the rich fauna of the hard gravelly and stony bottom of the channel immediately east of it. From this bottom a few rods east of the island the species listed in column ten of the table were taken as well as a variety of other forms of life including sponges, making a total of more than 25 species. A single haul of the dredge would sometimes bring up a bushel of sponges from this bottom. The soft grey or chocolate-colored mud beaches which are common about the Bay of Fundy represent another type of the intertidal zone on which molluscan life is rare. These grey muds contain very little organic matter and are quite different from the black mud of station 2 which is rich in organic matter. The mud facies of the intertidal zone is shown in fig. 2A.

Comparison of the poverty stricken molluscan fauna of soft grey muds or the lifeless drifting sand facies of the intertidal zone with the teeming life of the rocky beaches (see fig. 3) furnishes incontestable evidence of the paramount influence of the physical character of the bottom materials in determining the abundance and kind of marine life living on them. On rocky shores a single species of barnacle, *Balanus balanoides*, is sometimes represented by 3000 individuals to the square foot. The bottom control of faunas which is so easily observed in the intertidal zone is equally potent below low tide as I have already shown. The dependence of the oyster upon solid

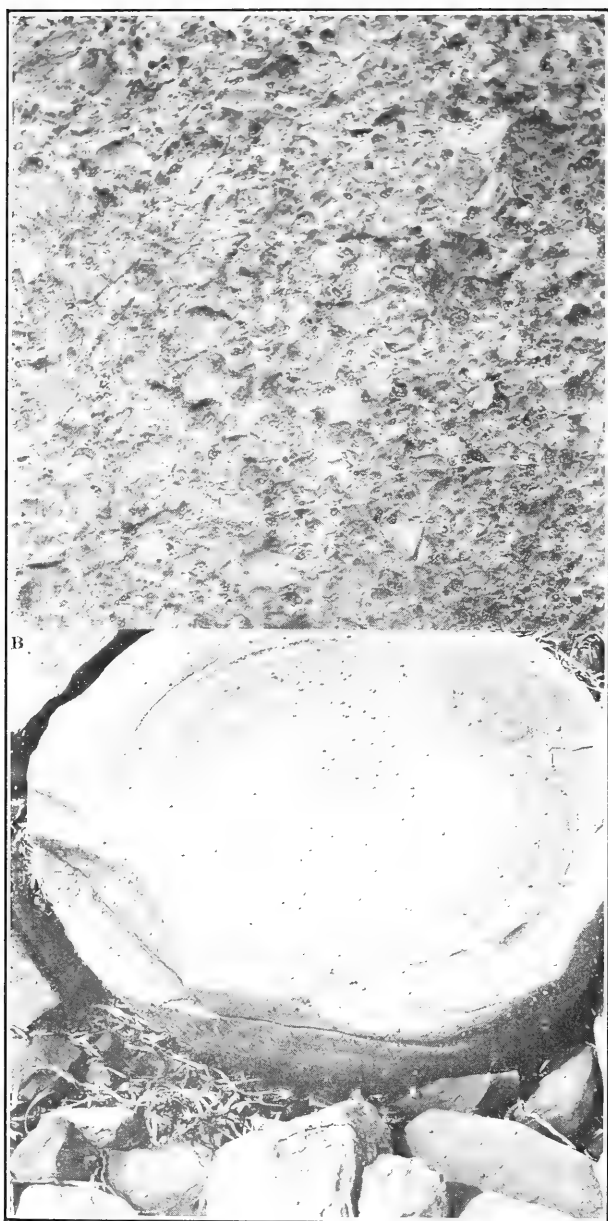


FIG. 3. A. Detail of vertical face of limestone ledge of the intertidal zone, with rich gasteropod fauna. Several hundred individuals to the square foot may often be counted on such a surface. Bic. Gulf of St. Lawrence. L. D. Burling, photographer.

B. Detail of beach shown in A pl. 1. figure shows average abundance of gasteropod life on the stony type of intertidal zone. H. I. Smith, photographer.

objects for attachment may be cited as a further illustration of this point. Keller* has observed 350 young oysters attached to a shell-surface 2 by $\frac{1}{2}$ inches, while soft mud bottom without solid objects is always barren of oysters.

It may be noted here that it is not the sedentary forms of life alone which are controlled in their distribution by the physical character of the bottom. It has long been known to deep-water fishermen that successful fishing was limited to a large degree to certain kinds of bottom. Ichthyologists are well aware that large schools of fish make their habitat over certain types of bottom and the U. S. Fish Commission includes in some of its recent reports, maps† showing the physical characteristics of the sea bottom on the continental shelf which are intended for the guidance of fishermen in selecting profitable fishing grounds. With reference to sand bottom these authors state that "no halibut fishing of consequence is to be expected on continuous fine grey sand bottom."‡ Again they remark that "ordinarily this kind of bottom (grey sand) does not carry fish."§ Gravel bottom and "broken bottom" composed of shale gravel, sand and mud in patches these authors speak of as "rich bottom" over which good catches of fish are to be expected. It is thus evident that the character of the bottom controls the distribution not only of the attached and sedentary forms of life but in large measure the free swimming forms as well.

The rate of sedimentation is another factor connected with bottom conditions which is important in limiting the habitat of attached invertebrates. A deposit of 12 inches of mud in four days on a freshly prepared oyster bed has been reported|| on the Gulf coast. No colony of attached shells could survive this rapid rate of sedimentation.

Bottom Compared with Latitude Control.

The high efficiency of bottom control of the composition of a faunal congeries is clearly indicated when compared with the effects resulting from differences in latitude on the composition of a fauna which are well known to be considerable. The contrast in composition between the Bay of Fundy Molluscan fauna and that of N. Labrador may be taken as an illustration of the influence of latitude in modifying faunal composition on the east coast of Canada. Through the labors of a number of workers extending over three-quarters of a century, the

* Louisiana Gulf Biological Station, Bull. 3, p. 28, 1905.

† W. L. Schmidd, E. C. Johnston, E. R. Rankin and E. Driscoll. Survey of the Fishing grounds on the coasts of Washington and Oregon in 1914. Rep. U. S. Comm. of Fisheries for 1914 (1915), Appendix VII, pp. 1-20.

‡ Ibid., p. 21.

§ Ibid., p. 19.

|| Idem., p. 37.

Acadian fauna of the Bay of Fundy is pretty well known. The boreal fauna of N. Labrador is comparatively little known but a representative collection compared with the fauna of the Bay of Fundy should give an approximate idea of the influence of latitude in differentiating the two faunas. I have selected for comparison with the Bay of Fundy fauna a collection from Ungava Bay made by Turner and determined by Dr. Dall.* The pelecypods and gasteropods of this collection include 17 species. Comparison of these with the entire known fauna recorded for the corresponding groups from the Bay of Fundy shows that only 53 per cent of the Ungava Bay fauna is common to the fauna of the Bay of Fundy. The entire recorded fauna of the Bay of Fundy probably represents every type of bottom that would be met with in Ungava Bay. Hence this factor would be negligible in this comparison and the difference in composition presumably represents the influence of latitude and the attendant differences in water temperature. In other words the difference in latitude of the two regions, which is about 18 degrees, results in a fauna at the northern locality 47 per cent of whose species are unknown in the Bay of Fundy.

If the faunal difference due to a latitude difference between Ungava Bay and the Bay of Fundy is compared with the faunal differences due to character of bottom which have already been shown from the tables for the west coast of Nova Scotia, it is seen that the latter are much more pronounced. The single example taken of the Labrador fauna shows a difference in faunal composition of 47 per cent resulting from a latitude difference of 18°. The tables given in this paper show that 80 per cent of a black mud fauna fails to appear on a gravel and rock bottom. In the case of a hard bottom fauna 100 per cent sometimes fail to pass over to a sand bottom habitat. The conclusion is therefore reached that differences in the physical character of the bottom are often even more effective than great differences in latitude in determining the composition of a fauna.

Bearing on Geology.

The geological significance of the observations recorded in this paper may be more clearly indicated if for the sake of illustration subsidence is assumed to occur which would lower the mouth of the Avon River in western Nova Scotia 100 feet below its present level. This would reduce the present strong currents so that the channel on either side the long barren sand bar, which now splits the lower end of the estuary, would fill with sandy mud to the top of the bar and eventually bury it under 30' or more of sediment of a type

* Proc. U. S. Nat. Museum, vol. ix, pp. 202-208, 1886.

very certain to be rich in molluscan shells. A hypothetical East-and-West cross section through the present mouth of the estuary in the year 10000 it may be inferred would show at the base a lens of sandstone one half mile wide and about 20' thick absolutely barren of fossils. Flanking and covering this barren sandstone would be a fossiliferous sandy shale resting on a fossiliferous conglomerate with a fauna closely allied to the shaly fauna above. It should be noted here that the materials for the barren sandstone and the fossiliferous conglomerate alongside it are already in place and are not hypothetical. Is it not probable that the astute geologist of this future time might conclude that the barren sandstone was separated from the fossiliferous conglomerate and shale by an unconformity and so infer an uplift followed by subsidence where there had been only uninterrupted subsidence? A mile or two from this hypothetical section he would find sections of shale containing very few fossils except U-shaped burrows made by a small crustacean, *Corophium volutator* (Pallas). Thousands of these would characterize every cubic yard of the shale and he might easily fail to realize that these brackish water beds, the shales and conglomerate with a marine fauna and the barren sandstone, represented different facies of the same stage of sedimentation.

It is pleasing to note, however, that there is a growing tendency on the part of paleontologists to give consideration to the ecological conditions under which fossil faunas lived. Twenhofel's work on "The Anticosti Island Faunas"* is an example of this tendency. He finds in Anticosti that "the faunas of the north and south shores show great differences which in every instance correspond to differences in lithology and hence to differences in the ecologic conditions at the time of sedimentation."

It is of the utmost importance that the paleontologist in using fossils for correlation should recognize and bear in mind the close relationship between the physical texture of the bottom and the kind of life living upon it. Recognition of this relationship will in no wise restrict him in using similarity of faunas as evidence of age equivalence in beds of similar lithologic type, but it should teach him to be extremely cautious when dealing with unlike lithologic types, in attributing differences between faunas to differences in age if stratigraphic considerations do not support such an inference. Instead of expecting the same type of fauna in synchronous deposits of widely unlike lithology he should look for faunal contrasts in which the faunal facies varies as widely as the lithologic facies.

Victoria Memorial Museum, Ottawa, Canada.

* Can. Geol. Survey Mus. Bull., No. 3, pp. 2, 11, 1914.

SCIENTIFIC INTELLIGENCE.

I. CHEMISTRY AND PHYSICS.

1. *The Manufacture of Gasoline and Benzene-Toluene from Petroleum and Other Hydrocarbons.*—W. F. RITTMAN, C. B. DUTTON and E. W. DEAN have published an abstract of Bulletin 114 of the U. S. Bureau of Mines and have added some supplementary information in regard to new developments in the "cracking" of oils on a commercial scale. In these processes the heavy oil passes down through vertical iron tubes where it is heated to a high temperature under high pressure. Large quantities of carbon are deposited in the tubes during the decomposition, and an important feature of the newly devised apparatus is a rotating "stirring rod" passing through the tube and provided with attached chains which scrape the inner wall of the tube and keep it free from carbon. The carbon falls into a receptacle at the bottom of the tube while the gases and vapors pass on to a condenser. Several tubes are heated together in a chamber by means of gas burners. Many experiments have been made in connection with the benzene-toluene process in regard to the most suitable size and length of the tubes and the best temperature and pressure. It has been found that each increase in the diameter of the tubes has given improved results, and in the latest plant tubes of $10\frac{3}{4}$ inch internal diameter have been employed, capable of converting 60 gallons of oil per hour per tube. For producing benzene and toluene it appears that a temperature between 650° and 750° C. is suitable while pressures up to 250 lbs. per square inch have been employed. For producing gasoline a lower temperature of about 500 to 575° C. is used with a pressure of about 250 to 300 lbs. per square inch. The yields appear to vary with the nature of the heavy oil employed. The yields of gasoline appear to vary between 10 and 30 per cent of the original oil, while the yields of benzene and toluene together were frequently from 5 to 9 per cent.—*Jour. Indust. and Eng. Chem.*, viii, 351.

H. L. W.

2. *A Rapid Method for the Determination of Copper and Iron.*—GRAHAM EDGAR has devised an interesting combination of well-known reactions for this purpose, where both metals are determined volumetrically in a single portion. The solution containing copper and iron, together with some sulphuric acid, is nearly neutralized with ammonia or sodium carbonate. It is then saturated with sulphur dioxide and heated until it begins to boil. Then a slight excess of standard solution of ammonium thiocyanate is added to precipitate all the copper. The solution is then boiled vigorously for ten minutes, while a current of carbon dioxide is passed through the solution. This operation is carried out in a flask. The stream of carbon dioxide is continued

while the liquid is rapidly cooled. The liquid is then filtered, preferably through asbestos, and the precipitate is washed with cold water. The filtrate is treated with some dilute sulphuric acid and a small excess of standard silver nitrate solution is added. Then the iron is titrated with potassium permanganate solution in the usual way. When the end point has been reached the color of the permanganate is removed by the addition of a trace of ferrous sulphate, and the excess of silver in the solution is at once determined by means of standard ammonium thiocyanate solution. The iron is calculated in the usual way from the amount of potassium permanganate used, while the copper is calculated from the amounts of ammonium thiocyanate and silver nitrate employed. The test analyses given by the author show remarkably accurate results, and the process seems to be a rapid one. It appears to the reviewer that there are possibilities for errors in this method, if improperly carried out, in the oxidation of the ferrous sulphate by the nitric acid introduced, and in the oxidation of silver thiocyanate acid by the permanganate.—*Jour. Amer. Chem. Soc.*, xxxviii, 884.

H. L. W.

3. *Colorimetric Determination of Acetylene and its Application to the Determination of Water.*—E. R. WEAVER has devised a method for the determination of small amounts of acetylene. It is based upon the color produced by allowing a gas containing the substance to pass through an absorbing liquid containing a little cuprous chloride, hydroxylamine hydrochloride and gelatine dissolved in a mixture of alcohol and ammonia. The color is compared with a standard solution of red dye or with a piece of ruby glass. For the details of the apparatus used, which is somewhat complicated, reference must be made to the original article. The method is very sensitive, and amounts of acetylene as small as 0.03 mg. may be detected, while amounts up to 2 mg. may be determined with an error of less than 0.05 mg. It was the main object of the investigation to devise a method for determining small amounts of water in volatile organic liquids and other things by its reaction with calcium carbide, but the results in this direction were unsatisfactory. However, a qualitative test for water, sensitive to less than 0.1 mg., may be easily made in this way.—*Sci. Paper, U. S. Bureau of Standards*, No. 267.

H. L. W.

4. *A Delicate Test for Copper.*—W. G. LYLE, L. J. CURTMAN and J. T. W. MARSHAL have investigated a reaction, which had been observed by Kudielka several years ago. It is based upon the insolubility of the copper salt of α -amino-*n*-caproic acid, $\text{CH}_3(\text{CH}_2)_4\text{CHNH}_2\text{COOH}$. A solution of this acid was prepared by dissolving 0.67 g. of the acid in 100° of water. Since free mineral acids interfere with the test, it is best to add some sodium acetate in making it. The precipitate is grayish blue, and the reaction is exceedingly sensitive, and as little as 0.004 mg. of copper in a volume of 3° can be detected with certainty. Mercury and zinc are the only other common metals which yield a pre-

precipitate under the proper conditions for the copper test. The interference of the mercury may be overcome by the addition of sodium chloride, while the zinc compound may be prevented from precipitating by increasing the acidity of the liquid. The reagent is characterized as more specific for copper than any heretofore proposed, and it possesses the advantage over the ferrocyanide test in the fact that small quantities of iron do not interfere with it.—*Jour. Amer. Chem. Soc.*, xxxvii, 1471. H. L. W.

5. *A Theory of Magnetism*.—Since the older theories of magnetism are not in complete accord with one another and since no single theory accounts for all of the experimental facts, much interest and importance attach to a theory which has been recently worked out in detail by R. GANS and which seems to agree with all observed phenomena. The fundamental model made use of in this theory is termed the "magneton" and is defined by Gans as a rigid system of electrons or negative electric charges. The magneton is supposed to be situated in the interior of a sphere which is uniformly charged with positive electricity, the total positive charge being equal numerically to the total negative charge constituting the magneton. Moreover, the center of mass of the magneton is assumed to coincide with the center of the containing sphere. The magneton itself does not have to be geometrically a figure of revolution. For example, a prism of square cross-section is used by Gans as an illustration of a form which possesses two equal principal moments of inertia but no geometric axis of revolution ("Figurenachse"). The results of the mathematical analysis may now be summarized.

When the magneton has no geometric axis of revolution, the excitation in a magnetic field is always diamagnetic.

The diamagnetic susceptibility is independent of the field strength and of the temperature when the three principal moments of inertia are all equal to one another. This phenomenon has been frequently observed.

If the principal moments of inertia have not all the same value then the diamagnetic susceptibility does depend upon both the field and the temperature. With the exception of very low temperatures, this has been found experimentally by Honda to be true.

A quantitative comparison of the theory with experimental data will give the number of magnetons in a gram molecule and also the values of the principal moments of inertia of the magneton.

The excitation is paramagnetic when the magneton possesses a geometric axis of revolution. The magnetic moment remains constant (as experience requires), since the magneton does not radiate, and it does not depend upon the temperature. The last theoretical deduction is in complete accord with the experimental discoveries of Weiss. In particular, at the absolute zero of temperature the magnetic moment of the magneton has a finite value (not zero). This too agrees with the experimental facts at

extremely low temperatures. Accordingly, for problems in statistical mechanics, it is not necessary to assume an absolute-zero energy.

Whereas pure diamagnetism can exist, such is not the case for paramagnetism. The latter is always accompanied by the former, since diamagnetism corresponds to thermal rotations about the equatorial axes. With weak fields and low temperatures paramagnetism may preponderate, but with stronger fields and higher temperatures it passes over to diamagnetism. This accounts for the phenomena of metamagnetism recently discovered by Weber and Overbeck.—*Ann. d. Physik*, vol. xlix, p. 149, Feb., 1916.

H. S. U.

6. *The Carriers of the Spectra of Hydrogen.*—By carefully weighing all of the experimental evidence associated with the Doppler effect in the canal rays of hydrogen, J. STARK has arrived at the following important conclusions. (a) The series spectrum and the band spectrum of hydrogen have different carriers. By "band" spectrum Stark means the so-called "second spectrum" or "many-line spectrum." (b) The carriers of the two spectra of hydrogen have the same mass as that of the hydrogen atom ($m = 1$). (c) The carrier of the series spectrum of hydrogen is the positive atomic ion. (d) The carrier of the band spectrum is the neutral hydrogen atom. (e) The neutral hydrogen atoms, while in a state of equilibrium and radiating sharp spectral lines, do not occur in appreciable numbers as displaced or "moved" particles in the canal ray stream. (f) The lines of the hydrogen bands in the canal ray beam are not excited by the collision of secondary canal rays but by the direct impact of the canal rays themselves.

Unfortunately the discussion is too long to be adequately reproduced in this place so that reference to the original paper must be made for the details of the argument.—*Ann. d. Physik*, vol. xlix, p. 179, Feb., 1916.

H. S. U.

7. *The Primary X-Ray Spectra of Iodine and Tellurium.*—Since the investigations of the high frequency spectra of iodine and tellurium, carried out independently by de Broglie and I. Malmer, led to conflicting results with regard to the proper sequence of these elements, the problem has been again attacked experimentally by MANNE SIEGBAHN. Moreover, since the earlier investigators made use of secondary radiations, and since, in general, the results obtained by this method are not as accurate as the ones obtained by using primary radiations, Siegbahn employed primary X-rays. The simple scheme of using a cooled silver anticathode on the surface of which a compound of iodine or of tellurium was produced (by placing the pure element in question on the silver disc and then warming) was found to work very satisfactorily. The spectrograms obtained by rotating a rock salt crystal showed two sharp lines for each of the elements, iodine, silver, and tellurium. The wave-lengths were based on that of the line β_1 of silver since this has been accurately determined as 0.5011×10^{-8} cm. corre-

sponding to an angle of "reflection" of $5^{\circ} 6.5'$. The wave-lengths of the α_1 and β_1 lines of iodine were found to be 0.437×10^{-8} cm. and 0.388×10^{-8} cm. respectively. The corresponding data for tellurium are given as 0.456×10^{-8} cm. and 0.404×10^{-8} cm. Consequently the succession of the elements should be tellurium-iodine, as de Broglie found and as would be expected from the chemical properties of these elements. When the atomic numbers for cadmium (48), indium (49), tin (50), antimony (51), tellurium (52), iodine (53), and barium (56) are laid off as abscissæ with the corresponding values of the square root of the reciprocal of the wave-lengths as ordinates, the points obtained fall very nearly on two parallel straight lines pertaining respectively to the α_1 and β_1 lines of the radiators. The α_1 locus lies nearer to the axis of atomic numbers than the β_1 graph. The question, therefore, seems to be settled in favor of the tellurium-iodine succession.—*Verh. d. deutsch. physik. Gesell.*, No. 1, p. 39, 1916. H. S. U.

8. *The Distribution of Intensity in Broadened Spectrum Lines*.—In a paper presented before the Royal Society of London J. W. NICHOLSON and T. R. MERTON made the following important statements. (1) Using a neutral-tinted wedge, the actual distribution of intensity in broadened spectrum lines can be accurately measured. (2) With this arrangement quantitative measurements of the hydrogen line H_α have been made, and quantitative observations of other lines of hydrogen, helium, and lithium. (3) The intensity-distribution of lines, broadened by condensed discharges and at high pressures, does not follow the well-known probability law known to obtain under certain specified conditions. (4) The broadening of H_α is symmetrical. (5) The most general characteristic of all the curves obtained is that their curvature is away from the axis perpendicular to the wave-length scale. (6) The existence of more than one component accords with the view that electrical resolution of lines is the origin of their broadening. (7) On the supposition of several components symmetrically distributed about the centre, the only general law consistent with the distribution of curvature is that of a sum of linear exponential terms, one for each component. (8) It is shown that in these circumstances discontinuities in the slope of the curve must occur. Those found in the curve for H_α are in quantitative accordance with those expected from available data with respect to electrical resolution. (9) Quantitative observations of H_β , H_γ , and the diffuse series of helium and lithium confirm the view that electrical resolution is the principal cause of the phenomena.—*Nature*, vol. xcvii, p. 73, March 16, 1916. H. S. U.

9. *Magnetic Declination in the United States for January 1, 1915*.—A new isogonic chart for this country, prepared by DANIEL L. HAZARD, has recently been issued by the U. S. Coast and Geodetic Survey. It is based upon a large number of observations, including those at more than 1000 new stations. The lines of equal annual change are given as well as those of equal declination.

II. GEOLOGY.

1. *Wisconsin Geological and Natural History Survey*; E. A. BIRGE, Director; W. M. O. HOTCHKISS, State Geologist.—Several bulletins have recently appeared from the Wisconsin Survey, including the following:

Bulletins XXVIII-XXXII, XXXVII-XL.—These bulletins are Nos. 2-6 and 7-10 of the Soil Series. The matter presented is designed to aid the agriculture of the state by giving the farmer a thorough knowledge of the soil with which he has to deal. The work has been carried on in coöperation with the U. S. Department of Agriculture, and the result will finally be reports for all counties, with series of soil maps. The first of the two volumes now issued embraces Waushara, Waukesha and Iowa counties with also the Bayfield Area and the north part of north-western Wisconsin; the second includes Fond du Lac, Juneau, Kewaunee and La Crosse counties. Soil maps in pockets accompany the volumes.

Bulletin XXXV. *Water Supplies of Wisconsin*, pp. xxii, 664; 5 pls., 72 figs.—This volume gives the results of an investigation of the water resources of the state, which has been carried on more or less continuously since 1903. It was first undertaken by A. R. Schultz of the U. S. Geological Survey, and his work, of which a brief account was given in 1905 (*Water Supply Paper* No. 114), has now been continued by Samuel Weidman for the Wisconsin Survey. The report has reference not merely to water for drinking purposes, but also that used in manufacturing, and finally for irrigation and water power. As indicating the importance of the subject, it is noted that more than one-half of the population of the state in the rural districts is supplied from shallow ground-water wells, and less than one-quarter, including private and public uses, is obtained from artesian wells. More than one-quarter of the population thus, of the large cities, get their water from lakes and rivers.

Bulletin XLIV. *Mineral Land Classification*. Pp. x, 378; 8 pls., 38 figs.—This bulletin is by W. O. HOTCHKISS assisted by E. F. BEAN and O. W. WHEELWRIGHT. It describes in detail an area in the northern part of the state on which no detailed geological work has been hitherto done, although sporadic exploration for iron ore was early made. The general geology of the region is presented, followed by two chapters on magnetic observations, having as their object the location of useful ores. A large part of the volume gives the details of the successive sections in the area under examination, with local maps.

2. *Canada, Department of Mines*.—Notwithstanding the constant drain upon the resources of Canada, due to the European war, the active investigation of the geology and mineral products of the Dominion goes on without interruption.

The more important of recent publications are noted in the following list (see earlier, vol. xl, pp. 87, 88).

(1) *Geological Survey Branch*; R. W. BROCK, Director. Summary Report of the Geological Survey, Department of Mines, for the calendar year 1914. Pp. viii, 201; 4 illustrations.

BULLETINS.—No. 34. The Devonian of Southwestern Ontario, by CLINTON R. STAUFFER. Pp. iv, 341 ; map in pocket, 20 pls. See this volume, p. 221, for detailed notice.

No. 36. Geology of the Victoria and Saanich Map-Areas, Vancouver Island, B. C.; by CHARLES H. CLAPP. Pp. viii, 143 ; 4 maps, 18 pls., 6 figs.

No. 50. Upper White River District, Yukon ; by D. D. CAIRNES. Pp. iv, 191 ; 3 maps, 17 pls., 2 figs. See this volume, p. 221.

No. 53. Coal Fields of Manitoba, Saskatchewan, Alberta, and Eastern British Columbia (revised edition) ; by D. B. DOWLING. Pp. 142 ; 1 pocket map ; 9 pls.

No. 58. Texada Island, B. C.; by R. G. McCONNELL. Pp. v, 112 ; 8 pls., 1 fig.

No. 60. Arisaig-Antigonish District, Nova Scotia ; by M. Y. WILLIAMS. Pp. vi, 173 ; 2 maps. See this volume, p. 222.

No. 64. Clay and Shale Deposits of the Province of Quebec ; by J. KEELE. Pp. ix, 280 ; 1 map, 34 pls., 13 figs.

No. 67. The Yukon-Alaska International Boundary, between Porcupine and Yukon River ; by D. D. CAIRNES. Pp. 111, 161 ; 2 maps, 16 pls., 2 figs.

No. 68. Geological Reconnaissance between Golden and Kamloops, B. C., Canadian Pacific Ry. ; by R. A. DALY. Pp. viii, 260 ; 7 maps, xlv plates, 4 figures.

No. 69. Coal Fields of British Columbia ; compiled by D. B. DOWLING. Pp. iii, 350 ; 23 diagrams, 1 map.

No. 72. The Artesian Wells of Montreal ; by C. L. CUMMING. Pp. v, 153 ; 1 map, 1 pl., 5 figs.

No. 74. A List of Canadian Mineral Occurrences ; by ROBERT A. A. JOHNSTON. Pp. iii, 275. This catalogue will be welcomed by mineralogists, as twenty-five years have passed since the earlier one by Hoffmann.

No. 76. Geology of Cranbrook Map-Area, B. C.; by STUART J. SCHOFIELD. Pp. vii, 245 ; 15 figs.

No. 78. Wabana Iron Ore of Newfoundland ; by A. O. HAYES. Pp. iv, 163 ; 28 pls., 4 figs.

No. 81. Oil and Gas Fields of Ontario and Quebec ; by WYATT MALCOLM. Pp. ii, 248.

MUSEUM BULLETINS.—No. 15. Gay Gulch and Skookum Meteorites ; by R. A. A. JOHNSTON. Pp. 31 ; 11 pls.

No. 17. Ordovician Rocks of Lake Timiskaming ; by M. Y. WILLIAMS. Pp. 9 ; 1 pl.

No. 18. Structural relations of the Pre-Cambrian and Palæozoic Rocks north of the Ottawa and St. Lawrence Valleys ; by E. M. KINDLE and L. D. BURLING. Pp. ii, 23. No. 1558.

No. 20. An Eurypterid Horizon in the Niagara Formation of Ontario ; by M. Y. WILLIAMS. Pp. 21, 5 pls.

No. 21. Notes on the Geology and Palæontology of the Lower Saskatchewan River Valley ; by E. M. KINDLE. Pp. 25 ; 4 pls.

No. 22. The Age of the Killarney Granite ; by W. H. COLLINS. Pp. 12 ; 1 pl., 1 fig.

(2) *Mines Branch.* EUGENE HAANEL, Director.

Summary Report for the calendar year ending December 31, 1914. Pp. ix, 232 ; 12 pls., 15 figs.

Preliminary Report on the Mineral Production of Canada during the calendar year 1915 ; prepared by JOHN McLEISH.—The results here stated show the extraordinary change brought about in the mineral industries in North America under the stimulus of war demand. The total value of mineral production in Canada amounted to \$138,500,000, only \$7,000,000 less than the maximum year of 1913, and \$10,000,000 more than 1914. The greatest increase naturally has been in the metals, the total value of which ran up, in 1915, to \$77,000,000, as compared with \$66,000,000 in 1913. The metals concerned in this change, in order of importance, are nickel, copper and lead ; the quantity of nickel, for example, being 50 per cent greater than in 1914, copper 35 per cent, and lead nearly 25 per cent. Of note also, is the development of the benzol and toluol, by-products from the coke-ovens. There was also activity in mining magnesite and chromium ores.

Special pamphlets give in detail the facts as to the production for the year 1914 of gold, silver, copper, nickel, etc. ; of iron and steel ; coal and coke ; cement, lime, clay products, stone, etc.

Other publications of importance are the following :

No. 291. Petroleum and Natural Gas Resources of Canada, Vol. II ; by F. G. CLAPP and others. Pp. viii, 404 ; 12 pls., 23 figs., 3 maps.

Products and By-Products of Coal ; by EDGAR STANSFIELD and F. E. CARTER. Pp. vi, 51 ; 7 tables.

No. 325. Salt Deposits of Canada and the Salt Industry ; by L. HEBER COLE. Pp. vii, 152, viii ; 26 plates, 25 figs., 4 maps.

No. 331. Investigation of Six Lignite Samples from Alberta ; by B. F. HAANEL and JOHN BLIZARD. Pp. viii, 110.

No. 334. Electro-Plating with Cobalt ; by HERBERT T. KALMUS, assisted by C. H. HARPER and W. L. SAVELL. Pp. vii, 69 ; 4 figs.

No. 344. Electrothermic Smelting of Iron Ores in Sweden ; by ALFRED STANSFIELD.

BULLETINS.—No. 12. Investigation of a reported discovery of phosphate in Alberta ; by HUGH S. DE SCHMID. Pp. iv, 38 ; 12 pls., 1 fig., 1 map.

No. 13. Description of the Laboratories of the Mines Branch of the Department of Mines, Ottawa. Pp. vii, 46 ; 60 pls., 12 figs.

III. MISCELLANEOUS SCIENTIFIC INTELLIGENCE.

1. *The National Academy of Sciences.*—The annual spring meeting of the National Academy was held at the Smithsonian Institution in Washington on April 17 to 19, and was largely attended. The following gentlemen were elected to membership : Gilbert Ames Bliss, of the University of Chicago ; Frank Schlesinger, of the University of Pittsburgh ; Gregory Paul Baxter, of Harvard University ; Marston Taylor Bogert, of Columbia University ;

Leland Ossian Howard, of the U. S. Department of Agriculture ; Alfred Goldsborough Mayer, of the Carnegie Institution, Tortugas, Florida ; Raymond Pearl, of the Maine Agricultural Experiment Station ; Phoebus A. T. Levene, of the Rockefeller Institute for Medical Research ; Otto Folin, of the Harvard Medical School.

The list of papers presented is as follows :

- S. J. MELTZER : On permeability of endothelia.
 I. S. KLEINER and S. J. MELTZER : The influence of morphin upon the elimination of intravenously injected dextrose.
 JACQUES LOEB : The sex of a parthenogenetic frog.
 SIMON FLEXNER : Finer mechanisms of protection from infection.
 EDMUND B. WILSON : The distribution of the chondrisomes to the spermatozoa in scorpions.
 VICTOR C. VAUGHAN : Further studies of the protein poison.
 ARTHUR KEITH : A new form of metamorphism.
 J. P. IDDIGS and E. W. MORLEY : Contributions to the petrology of Japan, Philippine Islands and the Dutch Indies.
 CHARLES R. STOCKARD : Hereditary transmission of defects resulting from alcoholism.
 W. B. CANNON : Recent observations on the activity of some glands of internal secretion.
 H. H. DONALDSON : Studies in the water content of the nervous system.
 GEORGE E. HALE : Some recent results of solar research.
 CHARLES E. ST. JOHN : An investigation of the suggested mutual repulsion of Fraunhofer lines.
 ARTHUR S. KING : Anomalous dispersion phenomena in electric furnace spectra.
 WALTER S. ADAMS : Illustrations of the new spectroscopic method of measuring stellar distances.
 HARLOW SHAPLEY : Some results with the new 10-inch photographic telescope.
 C. G. ABBOT and L. B. ALDRICH : The pyranometer, an instrument for the measurement of sky radiation.
 G. C. COMSTOCK : Invisible companions of binary stars.
 EDWIN H. HALL : Theory of electric conduction in metals.
 F. R. MOULTON : The evolution of the stars.
 A. O. LEUSCHNER : The minor planets discovered by James C. Watson.
 THEODORE LYMAN : The present state of knowledge of the extreme ultra violet.
 ROBERT A. MILLIKAN : A redetermination of e and N .
 CARL L. ALSBERG : The relation of investigational work to the enforcement of the Food and Drugs Act.
 J. WALTER FEWKES : Recent exploration on the Mesa Verde National Park, Colorado.
 ERWIN F. SMITH : Further evidence on the nature of crown gall and cancer, and that cancer in plants offers strong presumptive evidence both of the parasitic origin and of the essential unity of the various forms of cancer in man and animals.

In addition to the above, the following were also read in the *Symposium on the Exploration of the Pacific*, arranged by W. M. Davis:

- W. M. DAVIS : On exploration of the Pacific.
 J. F. HAYFORD : The importance of gravity observations at sea in the Pacific.
 L. J. BRIGGS : New method of determining gravity at sea.
 C. SCHUCHERT : The problem of continental fracturing and diastrophism in Oceanica.
 J. P. IDDIGS : Petrological problems in the Pacific.

G. W. LITTLEHALES: The extent of knowledge of the oceanography of the Pacific.

C. F. MARVIN: Marine meteorology and the general circulation of the atmosphere.

WM. H. DALL: On the distribution of Pacific invertebrates.

H. A. PILSBURY: Land mollusca of the Pacific.

W. G. FARLOW: Marine algæ of the Pacific.

D. H. CAMPBELL: Problems of the Pacific Floras.

J. W. FEWKES: The Pacific as a field for anthropological investigation.

The following biographies of former members were presented: Theodore N. Gill by WM. H. DALL; Edward S. Holden and Simon Newcomb by W. W. CAMPBELL.

The report of the committee on the Panama Canal slides was given by the chairman, CHARLES R. VAN HISE. This was followed by a paper on "The mechanics of the Panama slides" by H. FIELDING REID.

Another interesting feature of the meeting were the two public lectures on the William Ellery Hale Foundation, delivered by Professor HENRY FAIRFIELD OSBORN on "The origin and evolution of life on the Earth."

2. *The Northwest and Northeast Passages, 1576-1611*; edited by PHILIP F. ALEXANDER. Pp. xix, 211; maps and illustrations. Cambridge, 1915 (University Press).—The series of Cambridge Travel Books, of which this volume is one, has been undertaken for the use of the schools, with an object of presenting the English voyages of the sixteenth century which record "the deeds of the seamen who laid the foundation of Britain's sea power and her Colonial Empire." The period now covered includes the last quarter of the sixteenth, and the first decade of the seventeenth, centuries, and describes, with interesting illustrations, the voyages of Frobisher, Davis and Hudson, in the attempt to accomplish the northwest passage, and the voyage of Barents who attempted the northeast passage.

3. *University of Washington, Bureau of Industrial Research*.—A Bureau of Industrial Research has been recently established at the University of Washington in Seattle with Dr. Henry K. Benson as director. It will attempt to coördinate the research activities of the University, with a view to the best utilization of the resources of the State. A fellowship of \$2000 dealing with the iron and steel industry has been established, and others are contemplated.

4. *Summer "Assembly in Science" at the Scripps Institution, La Jolla, California*.—A "Summer Assembly in Science" at the Scripps Institution for Biological Research at La Jolla, on the sea coast near San Diego, will be tried this year by the University of California. "The purpose is to disseminate among teachers of biology and physical geography and others interested in modern science the discoveries and new points of view which are resulting from the investigations of this research department of the University, to acquaint the scientific pilgrims with the richly varied sea-life of the California coast, and to teach them how to read for themselves the books of nature as inscribed in the picturesque sea-coast of the San Diego region."

For further information, those desiring to avail themselves of the opportunities to be offered in the daily lectures, conferences and demonstrations, etc., should communicate promptly with Professor William E. Ritter, director of the Institution, at La Jolla.

OBITUARY.

DR. JOHN WESLEY JUDD, professor of geology at the Royal School of Mines from 1876 to 1905, died on March 3 at the age of seventy-six years. His productive work began in 1867 when he joined the Geological Survey and from this time on his activities extended over a wide field. Early interested in the new methods of investigating rocks with the microscope through the influence of Dr. H. C. Sorby, his contributions to the study of igneous rocks and the minerals contained in them were numerous and important. He also studied volcanic phenomena directly by visits to the Lipari Islands, Vesuvius, and elsewhere in Italy, Hungary and other fields; an excellent volume on "Volcanoes" was published in 1878. Further, his work included the handling of general geological problems; one important group of papers dealt with the Neocomian, and another with the oolites of the Midlands. Geological students were much aided by his revisions (1866 and 1911) of Lyell's Students' Elements of Geology. Another small but useful work in a different department is his "Coming of Evolution" published in 1911.

DR. HARRY CLARY JONES, since 1904 professor of physical chemistry at Johns Hopkins University, died suddenly at his home in Baltimore, Md., on April 9 at the age of fifty years. He was an active and successful worker in his chosen field and had published numerous important papers on solutions, their conductivities, viscosities and absorption spectra; on freezing and boiling point methods and allied subjects. He was also the author of several books, one of these an "Introduction to Physical Chemistry." Further he was associate editor of several scientific journals.

PROFESSOR ERIC GERARD of Liège, the electrician and writer on subjects in technical electricity, died in Paris on March 27, in his sixtieth year.

DR. E. HECKEL, professor of botany in the University of Marseilles, died recently at the age of seventy-two years.

PROFESSOR JULIUS WILHELM RICHARD, the distinguished German mathematician, has died recently.

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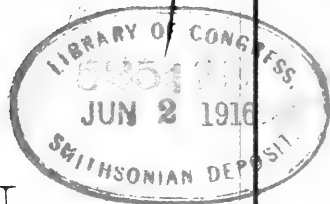
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FOURTH SERIES

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1916.

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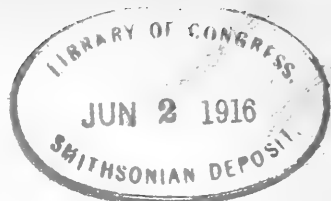
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[FOURTH SERIES.]

ART. XXXIII.—*The Several Forms of Calcium Carbonate*;
by JOHN JOHNSTON, H. E. MERWIN, and E. D. WILLIAMSON.

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Introduction.

THE prevalence of calcium carbonate as a constituent of the crust of the earth has led to a vast amount of discussion of the chemistry of its formation and of the stability relations of the several crystalline forms in which it occurs. The value, alike to the geologist and to the chemist, of an exact knowledge of the facts has also been repeatedly emphasized. The evidence has, however, been incomplete and in part contradictory or wrongly interpreted, and has never been presented systematically. It appeared, therefore, to be a useful task to give a coherent critical statement of the facts and to discuss the deductions which, in the light of present knowledge, may

legitimately be drawn from them; this the authors have endeavored to do. In regard to some of the doubtful points considerable experimental work has been done in order to verify or amplify the statements found in the literature;* there are yet some points which remain unsettled and must continue to remain so until more is known generally about the relations between unstable and stable forms and in particular of the factors which determine whether one form or another shall appear. This article, it is hoped, will help to dispel some of the errors and misconceptions which have been current, and to indicate some of the points upon which present knowledge is unsatisfactory.

At ordinary temperature calcium carbonate occurs in at least three anhydrous crystalline forms, viz., the two well-known forms calcite and aragonite, and another which we have designated μ - CaCO_3 . At atmospheric pressure and at all temperatures from 970° down to 0° (or lower), calcite is the stable form; under these conditions aragonite is relatively unstable, though its transformation to calcite may under certain circumstances be so slow as to be inappreciable, while the third form is still less stable and transforms more readily. Four other reputed forms, the so-called vaterite, conchite, ktypeite, and lublinitite, have also been described; there seems now to be little doubt that vaterite is a porous calcite, that conchite and ktypeite are porous aragonite, and that lublinitite is merely a special variety of calcite. In the literature, moreover, there is occasional reference to "amorphous" calcium carbonate as if it were a distinct form; this question also we discuss later. A number of hydrates of calcium carbonate have also been described; but with the exception of one, the hexahydrate, $\text{CaCO}_3 \cdot 6\text{H}_2\text{O}$, their definite existence is uncertain, since the experimental evidence leaves very much to be desired.

The authors' own experimental work has been concerned with the preparation and properties of the three indubitably distinct anhydrous forms and with the hexahydrate. Of these calcite alone is stable, at atmospheric pressure and at temperatures above 0° ; consequently the others persist only under circumstances such that their rate of transformation to the more stable form is small. Correlated with this, no doubt, is the fact that all methods for the preparation of the unstable forms are occasionally unsuccessful, and for no apparent reason; consequently it is difficult to make any categorical statement as to the factors which favor the production of any one form. The

* The authors have not attempted to give a reference for every statement cited, as it did not seem worth while, in view of the vast amount of literature pertaining to calcium carbonate, to trace each statement to its source; they realize moreover the probability that most of the ideas on which the present treatment is based have, in some form, been discussed previously.

nature of the precipitate, in this as in other cases, appears to be determined by the character of the first nuclei, but the factors which determine the character of these nuclei are still obscure. But, before taking up the methods of preparation, we shall discuss the tests by means of which the several forms may be distinguished from each other.

Methods for Identification of the Several Forms.

Measurements, with the aid of the petrographic microscope, of *optical* and *crystallographic* properties were relied on chiefly as a means of determining the forms of calcium carbonate present in precipitates, and of recognizing the presence of solid solution or of impurities. In most cases such methods are rapid and reliable, yet chemists have been slow to adopt them, in spite of the fact that in many cases they yield in a few minutes definite information which would be difficult—or impossible—to ascertain from purely chemical tests. A peculiar difficulty appears in the application of these methods to fine-grained aggregates of calcium carbonate, because of the extremely strong birefringence of the crystalline forms; nevertheless microscopical examination constitutes by far the surest criterion for the identification of separate crystals, and is much less uncertain than the others when applied to aggregates such as frequently occur in precipitates of calcium carbonate. In the latter case definite information may be obtained from a microscopical examination of the fine-grained aggregates before and after they have been heated for half a minute to 500–600°, i. e., from a test of the *stability* of the material, for under such treatment aggregates of calcite are not broken down, whereas aggregates (or single crystals) of aragonite or μ -CaCO₃ change to calcite, the aggregates changing always to a much simpler structure and often to a single grain of calcite.

Hitherto most writers have made use of other tests, which, however, have not always been free from ambiguity. For instance, *density* determinations have often been used; but if the results are to be capable of a definite interpretation, one must make certain that the sample used is homogeneous and free from bubbles, inclusions, or enmeshed material, and this can usually (though not always, e. g., in samples of “vaterite”) be ascertained by microscopical examination. In general, the density alone is not a safe criterion of identification,* though in particular cases it may be. Thus if the density of a sample of calcium carbonate is as high as 2.85, one is safe in considering that it is mainly aragonite; but if the density is much

* See, for instance, Johnston and Adams, J. Am. Chem. Soc., xxxiv, 563, 1912.

lower than this, one must pay particular attention to the homogeneity of the sample if a valid conclusion as to its constitution is to be drawn from the test. Sorby* used the density as a means of distinguishing calcite from aragonite in shells, etc.; his conclusions are indisputable in all cases in which he observed a high density, in materials which are essentially pure calcium carbonate.

Several so-called *chemical* tests have been proposed, and two of them have been quite generally adopted. These tests we shall now discuss briefly, for we have found that they cannot be relied on in all circumstances, and least of all where good tests would be most desirable, i. e., for differentiating the several forms when in a very fine state of division or as aggregates of fine particles. The two most generally used were suggested by Meigen;† they are as follows:

I. Aragonite immersed in a dilute solution of cobalt nitrate slowly becomes lilac and the color develops rapidly on boiling; calcite in a similar solution remains uncolored in the cold but slowly becomes blue on heating.‡

II. In a solution of ferrous sulphate calcite causes a yellow precipitate,§ aragonite a dark green precipitate.

Two other tests have been suggested by Thugutt.¶

III. Aragonite is turned pink by congo red or alkaline alizarin, but calcite remains uncolored.

IV. Aragonite turns red if treated for a second with 0.1 *N* AgNO₃ followed, after washing, by a 20 per cent solution of K₂Cr₂O₇.

V. Niederstadt¶ proposed to use as a more quantitative test the rate of precipitation of carbonates of various metals when calcium carbonate in one or other form is added to their salts; aragonite is stated to be more active in precipitating Mn, Zn and Fe, calcite in precipitating Cu, Pb and Ag. He asserts, for instance, that if one gram of calcite or aragonite powder (its degree of fineness and homogeneity of size are not specified) is added to a boiling solution of manganese sulphate, then in five minutes 74 per cent of the theoretical amount will be precipitated if the powder is aragonite but only about 1 per cent if it is calcite.

Of these, the test which has been most frequently employed is the cobalt nitrate test. Some of its limitations should be

* H. C. Sorby, *Quart. J. Geol. Soc.*, xxxv, 56, 1879.

† W. Meigen, *Centralblatt Min. Geol.*, 1901, 577.

‡ According to Lange (*Inaug. Diss.*, Freiburg, 1904) the differences in color are due to the formation of basic cobalt carbonates differing in composition.

§ In some books the erroneous assertion is made that this is ferric hydroxide. It is somewhat difficult to state the precise nature of these two precipitates; both are probably hydrous or basic ferrous carbonates.

¶ Thugutt, *Centralblatt Min. Geol.*, 1910, 786.

¶ Niederstadt, *Z. angew. Chem.*, xxv, 1219, 1912.

considered. Meigen* himself notes that barium or strontium carbonate and precipitated basic magnesium carbonate give the same indications as aragonite, dolomite the same as calcite. Krentz† mentions that cerussite (PbCO_3 , orthorhombic) and barytocalcite ($\text{BaCO}_3 \cdot \text{CaCO}_3$, monoclinic) do not color in the solution but alstonite ($(\text{Ba}, \text{Ca})\text{CO}_3$, orthorhombic) does. Panebianco‡ has pointed out that mixtures of aragonite and calcite containing as little as 5 per cent of the former are by this test indistinguishable from aragonite. Hutchinson§ observed that the presence of iron as an impurity masks the color. Skeats|| states that calcium phosphate gives a blue color resembling that given by aragonite. We have found that the μ form of calcium carbonate and the hydrated magnesium carbonate,¶ nesquehonite, behave like aragonite. It is obvious, therefore, that a considerable knowledge of the material tested is required before the test becomes useful.

In the case of test II we found that the color of the precipitate depends upon the concentration and CO_2 content of the solutions; in support of this a few experiments carried out with equivalent solutions of FeSO_4 and Na_2CO_3 may be cited: 0.01 N solutions of FeSO_4 and Na_2CO_3 when mixed give a green precipitate; 0.002 N solutions give a green solution from which a yellow precipitate slowly settles; 0.0001 N solutions give a yellow solution, and in the course of a few minutes a yellow precipitate. If the CO_2 pressure be raised, or if bicarbonate be used instead of carbonate, the yellow precipitate begins to appear at a higher concentration of the reagents; thus with a much stronger solution of FeSO_4 a green precipitate was not obtained until the concentration of KHCO_3 was 0.03 N , and even then it was yellowish-green at first.

* W. Meigen, Neues Jahrb. Min., 1903, ii, 19.

† S. Krentz, Min. petr. Mith., xxviii, 487, 1909. He considers that crystal symmetry is the dominating factor, carbonates isomorphous with calcite or aragonite giving either the corresponding reaction or none. But this view is not, in our opinion, justified by the facts, for the lilac precipitate is not oriented by the aragonite.

‡ G. Panebianco, Rivista Min. Crist. ital., xxviii, 5, 1902.

§ A. Hutchinson, Min. Mag., xiii, p. xxviii, 1903.

|| E. W. Skeats, Bull. Mus. Comp. Zool., xlii, 53, 1903.

¶ The magnesium of the calcitic hard parts of some (possibly of most) organisms does not give the lilac color reaction and is, therefore, in all probability present as anhydrous carbonate, either as dolomite or magnesite. This deduction is based on tests made on the following material analyzed by Clarke and Wheeler (Proc. Nat. Acad. Sci., i, 552, 1915, and later papers) and selected for us from specimens in the U. S. National Museum by Dr. W. L. Schmitt. Optical examination showed this material, which contains from 7 to 12 per cent magnesia reckoned as anhydrous carbonate, to be fibrous calcite with principal refractions of 1.49 and 1.65-1.66. Slight porosity probably accounts for the fact that the refraction is not significantly changed by the magnesia. The forms tested are: *Lepidisis carophyllia*, *Corallium elatior*, *Tubipora purpurea*, amongst the alcyonoids, and the alga *Goniolithon Acropetum*.

Analogous results were observed when solutions of cobalt salts were mixed with solutions of alkali carbonates.

The other tests proposed depend even more obviously on the state of subdivision and rate of dissolution of the carbonate. The latter is the only factor, so far as one can see, in Niederstadt's test, for the difference in *solubility* of calcite and aragonite is, as we shall see, so small that the difference in concentration of the two solutions can hardly be a factor in the result. It may be that the phenomenon of isomorphism plays a rôle here, in the sense that a carbonate isomorphous with that already present will tend to precipitate on the surface of the latter and thus to diminish its surface and consequently the rate of precipitation; but there would seem to be little likelihood of giving a definite and reasonable account of this matter until more is known of the factors which determine the formation and growth of crystals.

In the opinion of the authors, these chemical tests should not be used alone because they are indecisive, particularly so where they would be most useful; namely, for the characterization of fine-grained material which may carry something that interferes with the test; this opinion is based in part upon the above observations, in part upon the fact that some of the factors upon which these tests depend are very difficult to control. These factors are: concentration of reagent, temperature, CO_2 pressure (hence acidity, for these are dependent variables); the size of grain and stability of the precipitate formed; and in particular the rate of dissolution of the calcium carbonate—which in turn depends upon temperature, crystalline form, state of subdivision, and constitution of the solvent medium. Moreover, while these tests can be so carried out as to yield trustworthy indications with good crystals of calcite and aragonite, they cannot be trusted when applied to less homogeneous material such as may be obtained from precipitation experiments. Such material, even when minute irregular aggregates are present, usually yields to optical methods, though these methods may be uncertain when there are interlocking small grains or (as in "vaterite") inclusions of submicroscopic size; in such cases we must use as a basis all the criteria possible and, bearing in mind their several limitations, draw such conclusions as are admissible from the evidence as a whole.

CALCITE ($\beta\text{-CaCO}_3$).

Under all the conditions which have hitherto been studied, with the exception noted below, calcite is the stable form of CaCO_3 ; for it is the least soluble at ordinary temperatures, and at about 400° the other forms go over rapidly into it. It is

therefore the stable form at all temperatures from 0° (or lower) up to 970° , at which temperature—and under the requisite pressure of carbon dioxide to prevent dissociation into free lime and carbon dioxide—Boeke* observed the occurrence of a reversible change into another form, called by him α -calcium carbonate, which apparently differs very little crystallographically from calcite.

Calcite is the general product from slow precipitations, for special procedures must be adopted for the preparation of the unstable forms, and even then calcite occasionally precipitates instead of the desired less stable form. If either of the other two pure forms is left in contact with an aqueous solution—or indeed, with any liquid in which it dissolves—or if it is heated alone, the ultimate product is calcite.† The hexahydrate changes rapidly through solution in its water of crystallization into fine rhombs of calcite even at room temperature.

The properties which serve to characterize ordinary calcite‡ are so well known that they need not be recounted here; they are collected with those of the other forms of CaCO_3 in Table 4. Attention is called to a special habit of calcite which appeared in one experiment (see Table I, No. 34). The important question of its solubility will be discussed later.

ARAGONITE (λ - CaCO_3).

At the pressure of one atmosphere aragonite is, to judge from the available evidence, essentially unstable at all temperatures; it may possibly be stable at some temperature below 0° (upon this point there is no direct experimental evidence one way or the other) in which region it would be hard to secure decisive evidence by reason of the extremely slow rate of reaction. Moreover, it may have a stable region of existence at high pressures, but with regard to this too there is no experimental evidence. As a consequence of this instability, it is at the present time impossible to specify any limiting condition which determines absolutely the precipitation of calcium carbonate as aragonite. A large amount of work§ has been done on the conditions under which aragonite may form, yet no general correlation of this evidence with specific factors is discernible. As has long been known, aragonite is formed if the precipitation is carried on at a temperature approaching the boiling point of water, or in presence of a salt of a metal which yields

* Boeke, Neues Jahrbuch Min., 1912, i, 91.

† With regard to the crystallographic character of this calcite, see p. 500 *postea*.

‡ The properties of aggregates of calcite are treated under "vaterite."

§ In particular by Vater, whose results appear in a series of papers in Z. Kryst., between 1893 and 1901. A summary of the literature may be found in Doelter's "Handbuch der Mineralchemie," i, 346.

a carbonate—e. g., PbCO_3 or SrCO_3 —isomorphous with aragonite. Warth* states that aragonite is precipitated from alkaline solutions at ordinary temperatures, but he was mistaken in this conclusion because he did not use optical methods of identification, but relied on the chemical tests which, as we have shown, would not enable him to distinguish aragonite in such material with any degree of certainty from the other forms.† Many attempts have been made to find some relation between the precipitation of aragonite and the substances present in the solution, apart from those which yield carbonates isomorphous with the other forms of calcium carbonate. But to the authors the results seem inconclusive; for one thing, too few experiments were performed, and for another, precipitations carried out under apparently similar conditions do not always yield the same result, as we have found. This is perhaps not surprising if we consider that we are dealing with the appearance of an unstable form, which however differs but little in solubility from the stable form, and that the factors which really determine crystal structure and habit are far from being clearly understood yet. It has been considered that the presence of salts of magnesium‡ or of ammonium§ favors the formation of aragonite, but the main criteria used in these identifications were the chemical tests which, as we have shown, are ambiguous; we have performed a large number of experiments designed to test this question but we have been unable to discover any definite effect of the presence of magnesium or ammonium salts. Indeed we tried out the effect of each of the other major constituents of sea-water, but were unable to note any specific effect except in the case of sulphate;|| to this point we shall return later. Moreover the statement, frequently met with, that 30° is a limiting temperature above which aragonite, and below which calcite, is precipitated, has no foundation in fact.

Our best crystallized aragonite was made by slow precipitation in hot water at a temperature of $85\text{--}90^\circ$, a method which is successful nearly always. The procedure is as follows: Two burettes are fastened above a 800cc beaker containing water (or a solution of the salt whose influence is to be investigated) maintained at the proper temperature and provided with an efficient

* Warth, *Centralblatt Min. Geol.*, 1902, 492.

† By reason of this same circumstance the conclusions of Meigen (*Neues Jahrb. Min.*, 1903, ii, 19), of Linck (*Neues Jahrbuch, Beil. Bd.*, xvi, 495, 1903, and of others, are open to question.

‡ G. Linck, *Neues Jahrbuch, Beil. Bd.*, xvi, 495, 1903; F. Cornu, *Oesterr. Z. Berg. Hüttenwesen*, lv, 1907; F. Vetter, *Z. Kryst.*, xlviii, 45, 1911.

§ J. Peine, *Inaug. Diss.*, Jena, 1913; abstract in *Neues Jahrbuch*, 1915, i, 309.

|| Peine varied his sulphate concentration concurrently with the others, but omitted to take this variation into account in interpreting his results. Moreover he identified certain six-sided crystals or aggregates with aragonite, whereas they were undoubtedly the form designated by us the μ -form.

stirrer, in such a way that liquids dropped from the burettes will enter the beaker on opposite sides, and so mingle only in the body of the liquid; these burettes contain equivalent (usually 0.1 or 0.2 *N*) solutions of calcium chloride and potassium carbonate respectively, and the rate of dropping is so adjusted that a gram of carbonate is precipitated in two or three hours. It is essential that the two solutions should mingle only in the body of the liquid contained in the beaker—in other words, that the precipitation be the result of mixing effectively very dilute solutions;* for otherwise the precipitate will be so fine-grained that its definite identification will be difficult, if not impossible. Moreover for many other purposes, e. g., for determinations of solubility, it is very desirable to have fairly coarse-grained material in order that it may be adequately washed and dried, and easily handled.

Aragonite is precipitated, as is well known, even at ordinary temperature in a solution of a salt from which a carbonate isomorphous with aragonite may be precipitated; in this case it is necessary either that the salt be in sufficient concentration to insure that the foreign carbonate is precipitated first, or that it come down in solid solution with the aragonite. Aragonite, precipitated in presence of a lead salt, formed around nuclei of cerussite (PbCO_3) in parallel orientation; with the carbonates of strontium and barium the effect is not visible either by reason of their similarity to aragonite in refringence or because homogeneous mix-crystals are formed. The isomorphous carbonate is in all probability ineffective in inducing the formation of aragonite unless it is actually being precipitated when the aragonite begins to separate. Therefore in order to insure the appearance of aragonite by seeding with PbCO_3 it is best to wait until the solution in the beaker is nearing the point where precipitation would begin and then to add enough lead nitrate solution to cause PbCO_3 to form; since the solution is already supersaturated with respect to aragonite, its precipitation by this means is induced at once. We have found calcite deposited on cerussite (see Table I, No. 17) in precipitations in which these conditions probably did not obtain; it follows therefore that the addition of a few previously prepared crystals (of PbCO_3 or of aragonite itself) will not always produce the desired result. These details are given because Vetter† casts doubt on the efficacy of seeding as a means of insuring the appearance of aragonite.

When slow precipitations, carried out as described above, are made in a medium at a temperature of 80–90°, no isomor-

* For the rationale of this process, see Johnston, *J. Am. Chem. Soc.*, xxxvi, 16, 1914.

† Vetter, *Z. Kryst.*, xlviii, 45, 1911.

phous nucleus is required to produce aragonite. Under these circumstances it separates as minute prismatic forms, occasionally as fine-textured aggregates of irregularly radiating fibres which could be recognized only by refractive index determinations on fragments of very small size broken off from these aggregates. These crystals when heated lost the theoretical percentage of weight and therefore are pure aragonite; their optical properties are given in Table IV.

If the precipitation is carried out at a temperature of about 60° , the product is a mixture of pure aragonite mixed with $\mu\text{-CaCO}_3$, which can be separated by a flotation method; but at temperatures lower than this, the product is a mixture of $\mu\text{-CaCO}_3$ and calcite, except in presence of sulphate in which case the product consists in part of aragonite containing some proportion of sulphate, even when the temperature is less than 60° . Thus when calcium sulphate is used instead of calcium chloride, or when potassium sulphate is admixed with the potassium carbonate solution, or when solid calcium sulphate is present in the medium during precipitation, the prisms obtained, if well-formed, have a refractive index lower by about 0.01 in each direction; the crystals, though perfectly clear,* contain sulphate, in two analyses 1.2 and 1.4 per cent reckoned as CaSO_4 . Something very like this occurs in nature; for in a stalactite from a cave near Luray, Virginia, composed partly of aragonite, there was a thin layer which had optical properties nearly identical with those of the above artificial product containing sulphate, but the total quantity was so small that a satisfactory chemical analysis of it could not be made. The inference from this is that aragonite is able to take up some proportion of calcium sulphate in solid solution; on this basis one is enabled to account more readily for certain observations, for the presence of sulphate in solid solution might reduce the solubility of aragonite to such an extent as to render it not unstable with respect to calcite in solutions containing sulphate. We have made a large number of experiments on this influence of sulphate; and have obtained undoubted aragonite at temperatures as low as 19° , from solutions containing sulphate (see Table I, No. 23). This aragonite was difficult to identify, for although it consisted of very small needles which superficially resembled the usual precipitates of aragonite, its *apparent* refractive indices were very low, ranging down to 1.51 and 1.65 respectively, and varied with the conditions of precipitation. It was surmised that this variation was caused by a variation in the proportion of sulphate present, but analyses showed that the sulphate content

* When these clear aragonite crystals were heated, the calcite formed was clouded by inclusions.

about 1 per cent) of the crystals was practically the same as that of the well-formed crystals which separated at 60° C. Closer examination showed that these needles and associated forms* were really aggregates of nearly parallel fibers; we conclude therefore that the differences in apparent refractive index are to be ascribed to porosity.

These experiments indicate that it is the sulphate, and not the magnesia or other radicles present, which induces the formation of aragonite in the sea, though it may well be that, concurrently with this, other factors operate in the same direction; and it is entirely possible that to this admixture of sulphate is due the apparent preservation of aragonite as such for long periods in sea-water.

Aragonite when dry can be kept for an apparently indefinite period at ordinary temperature, as at 400° the inversion requires several hours. In presence of water pure aragonite transforms through solution very slowly; a sample shaken up with water at 25° only began to show an appreciable change after 31 days. In another experiment aragonite enclosed with water in a sealed tube was heated on a steam bath for two weeks and then left at ordinary temperature for upwards of two years; when examined, it proved to be still mainly aragonite although a few rhombs of calcite had formed on the walls of the tube. In accordance with this slow rate of transformation, we found that we could form crystals of aragonite on the faces of a large calcite crystal, merely by placing the latter in the beaker during the precipitation; cases of this phenomenon are known in nature. This cannot be done in presence of any appreciable amount of really fine-grained calcite, in which case the precipitate will consist largely or wholly of calcite, even under conditions which otherwise would yield aragonite;† indeed we have attributed the failure of some of our experiments to the presence of calcite dust in the laboratory atmosphere. The presence of calcite grains to serve as nuclei, from whatever source derived, will hasten naturally the transformation of aragonite in water; that such grains were present is the only plausible explanation of certain cases in which the transformation went rapidly. Similarly the inability of Foote‡ to conduct his determinations of relative solubility at temperatures higher than about 50° indicates that some calcite was present

* Aggregates with similar shape and structure, but different refraction, appear also in precipitates of calcite.

† Cf. Vetter, *Z. Kryst.*, xlviii, 45, 1911, who found that, whereas nuclei of aragonite might fail to bring it down under conditions under which it would not normally come down, nuclei of calcite always resulted in the precipitation of calcite.

‡ H. W. Foote, *Z. physik. Chem.*, xxxiii, 740, 1900.

in his aragonite ; for, as noted above, pure aragonite can be kept for days at 100° without appreciable transformation.



In the earlier experiments, especially those made about 25°, we observed that the precipitate contained a small proportion of scale-like aggregates and hexagonal plates differing from the bulk of the precipitate ; one refractive index was found to be about 1.56, and it was noted that these aggregates gave the same color tests as aragonite. One day, however, in endeavoring to prepare good crystals of calcite, we found a considerable proportion of this material which was, moreover, in better formed crystals ; and successive experiments yielded a quantity of it. Subsequently still better crystals of it were obtained, mixed with aragonite, by conducting precipitation experiments at about 60°, and this appears to be the best temperature for its preparation. It is, however, impossible to specify the optimum conditions for its appearance, for the result appears to be, so far as we are now concerned, a matter of chance and will probably remain so until the obscure determining factors shall have been ascertained.

One obvious prerequisite for the precipitation of an unstable form such as $\mu\text{-CaCO}_3$ * is that one must have a solution which is virtually supersaturated with respect to both calcite and aragonite, which are more stable, and hence less soluble than is $\mu\text{-CaCO}_3$; so that one must endeavor to minimize the effect of those factors which tend to relieve supersaturation†—particularly to avoid the presence of nuclei of the less soluble (more stable) forms, and violent shaking of the solution. Moreover in the endeavor to prepare large crystals of such an unstable form, one is between the devil and the deep sea ; for the slow precipitation necessary to the formation of large crystals also favors the transformation to the more stable form.

This form, which we have designated $\mu\text{-CaCO}_3$, is contaminated, when prepared as above, by calcite or aragonite ; from either of which, however, it is easily separated by flotation in a liquid of density about 2.6. Our products, purified in this way, still contained a small proportion of the more stable form, sufficient nevertheless to render illusory any measurements of the solubility of $\mu\text{-CaCO}_3$. The material was dried at 120°—a process which did not affect its appearance in any way—and analyzed, with the following results :

* A similar remark applies to the precipitation of any unstable form ; it will be discussed more fully *postea*.

† With respect to these factors see S. W. Young, J. Am. Chem. Soc., xxxiii, 148, 1911 ; S. W. Young and R. J. Cross, *ibid.*, 1375.

	I	II	Required for CaCO_3
Loss on heating.....	43.9	44.2	44.0
CaO from precipitation as oxalate..	56.1	56.2	56.0
CO_2 by direct absorption.....	43.2*		44.0

There is thus no doubt that it is really CaCO_3 ; its density† proved to be 2.54, but this value may be slightly low because it was determined on material which was partly fibrous or platy. This, together with its optical properties, suffices to characterize it as a distinct modification of CaCO_3 .

$\mu\text{-CaCO}_3$ varies greatly in appearance in different preparations. The smallest grains distinguishable by the microscope are hexagonal plates with faces either plane or with six radiating ribs. When a diameter of about 0.01mm is attained the plates usually cease to grow as units and become the nuclei of larger plates or aggregates which reach a maximum observed size of 0.07mm . These larger plates or aggregates are almost always thickened in the middle by either a parallel growth of smaller plates, a thickening of the radiating ribs, or overlapping of plates that are obliquely radiating. In the latter case the aggregates, though still roughly hexagonal in cross section, become lens shaped‡ or broadly elliptical in vertical section. The radiating plates are often found arranged in these aggregates so that the opposite triangular segments of the aggregates seen flatwise extinguish together, and give an apparently biaxial interference figure, $2E = 35^\circ\text{--}40^\circ$, with the plane of the optic axes parallel to the external sides of the triangles. But aggregates which do not show this regularity of extinction and the plates and star-shaped forms give a uniaxial positive interference figure. This form of calcium carbonate, therefore, is hexagonal. The refractive indices of well-formed plates were found to be 1.550 and 1.650, within about ± 0.005 ; the plates were held edgewise by mounting them in viscous mixtures of rosin and piperine of standard refraction. When measured on lens-shaped aggregates both apparent refractive indices are about 0.01 less than the true value; analysis of such aggregates showed that a little water is enmeshed among the non-parallel plates.

$\mu\text{-CaCO}_3$, when dry, persists indefinitely at room temperature, as far as we can judge; when heated alone, it goes over into calcite, both plates and aggregates commonly producing a single calcite grain. In presence of water at ordinary temper-

* The experimental errors all tend to a low result, especially when one is working, as here, with a small weight of substance.

† As determined by the pyknometer described by Johnston and Adams, J. Am. Chem. Soc., xxxiv, 567, 1912.

‡ The aggregates sketched by H. Vater (Z. Kryst., xxvii, 486, 1897) were probably this form of calcium carbonate.

ature our products also transformed rapidly; but it is an open question how rapidly pure μ - CaCO_3 , free from admixture of a more stable form, would be changed. On the basis of the chemical tests alone it would be indistinguishable from aragonite, though easily differentiated by its density and positive optical character.* In our experiments this form has been more easily recognizable optically than calcite or aragonite when the latter were in aggregates.

This form has undoubtedly been present in the precipitates of previous investigators, of Peine in particular, but has been confused with aragonite† by reason of the fact that it gives the same color tests; to this circumstance are to be ascribed statements as to the formation of aragonite under certain conditions (e. g., in presence of magnesium salts at low temperatures), statements which we have been unable to confirm in spite of repeated trials.

Other Reputed Forms of Calcium Carbonate.

1. *Vaterite*.—Vater‡ has described precipitates obtained from series of diffusion experiments, usually in presence of an alkaline solution containing barium; these products were fibrous aggregates, usually nearly spherical, with a density of 2.54, containing, however, some proportion of barium. He considered this material to be a new modification of CaCO_3 ; and it was subsequently called “vaterite” although there is no record of its occurrence as a mineral and no proof that it was a single definite crystalline species. Indeed, Vater observed the presence of occasional lens-shaped aggregates and hexagonal plates, which, as is now evident from our work, are certainly identical with the μ -form described above. On repeating some of Vater's experiments, we failed to obtain products identical with his; but we found later that such spherical aggregates can be prepared quite readily by slow precipitation, in an alkaline medium.

The best practical way, according to our experience, is as follows: dissolve 2 grams KOH in 600^{cc} water, and drop in from the burettes equal volumes of 0.1 *M* solutions of CaCl_2 and K_2CO_3 at such a rate that about 30^{cc} of each solution is added in an hour; the stirring must not be too violent, and care must be taken that no grains of calcite find their way into

*Lacroix (Compt. rend., cxxvi, 602, 1898) observed positive interference figures in thin sections of certain pisolites. He considered the mineral of the pisolites to be a new form of calcium carbonate (see “Ktypeite”).

†See for instance, G. Linck, Neues Jahrb. Min., Beil. Bd., xvi, 495 (1903); H. Warth, Centr. Min. Geol., 1902, 492; F. Cornu, Oesterr. Z. Berg. Hüttenw., lv, 596; J. Peine, Inaug. Diss. Jena, 1913.

‡H. Vater, Z. Kryst., xxvii, 477, 1897, and subsequent papers.

the solution. By using the larger particles from one experiment while still moist as nuclei in a second, one can increase somewhat the size of the aggregates. When magnesium salts were present, spherical aggregates* were obtained also; this is contrary to the statements of some previous investigators,† who may, however, have erred by reason of faulty methods of characterizing their products.

A test supposed to differentiate "vaterite" from calcite and aragonite was proposed by Spangenberg‡ and later "modified" and used by Peine;§ it consists in boiling the material with distilled water for a period of from 15 minutes to 2 days and observing whether new rhombs of calcite have appeared, on the basis that under these conditions "vaterite" would dissolve and recrystallize. But Peine himself states that this test fails sometimes. Many of the precipitates, however, contained material which from his own description we identify as the μ -form; and doubtless this material was transforming.

The fibrous aggregates, prepared as described above, are not all spherical, but appear in many shapes some of which alone are indistinguishable from single crystals. Many of the spherulites show a zonal structure, while practically all are not completely homogeneous throughout their mass; a few of them are perfect, and nearly all of them show in parallel polarized light the typical dark cross with a series of colored rings. The maximum path difference was found to be at a distance from the center of about 0.62 of the radius of the spherulite; this maximum was 3.4 wave-lengths at 650μ in one sample of spherules 0.03^{mm} in diameter. From the length of the path through the sphere where the path difference is greatest, the "double refraction of the spherulite" considered as a unit was calculated to be 0.092. It proved impossible to separate these aggregates into fragments of single crystals; so that it was a matter of considerable difficulty to come to a definite decision as to whether these aggregates constitute a distinct crystalline modification of calcium carbonate or are merely very fine-grained aggregates of fibres of one of the other forms. We shall now discuss the evidence bearing on this question.

In a few preparations spherulites of sufficient size—about 0.03^{mm} diameter—were found from which, by crushing, we obtained radial splinters having parallel extinction, negative

* The character of this product was such that no useful information could have been derived from a chemical analysis; so none was attempted.

† Cf. p. 480 *ante*.

‡ K. Spangenberg, *Z. Kryst.*, lii, 529, 1913.

§ J. Peine, *Inaug. Diss.*, Jena, 1913, p. 13.

elongation, and maximum and minimum refractive indices* of 1.62 and 1.47. The material, when dried at 120°, lost only an insignificant amount of water, and retained its original optical properties; its density proved to be 2.51, considerably lower therefore than aragonite (2.9) and calcite (2.7) and somewhat lower than μ -CaCO₃ (2.54). These several properties thus differ so much from those of the other forms that it would seem that this material is a distinct form.

But there are other lines of evidence which are opposed to this conclusion. A complete analysis of the material, dried at 120°, showed that it was CaCO₃, with about 4 per cent of water and about 1 per cent KOH.† Now such an amount of water (which would be about 10 per cent by volume of the material) if held as such in submicroscopic interstices among the radiating fibres of calcite would reduce the density and refractive index of the latter, yielding apparent values corresponding very closely to those observed for "vaterite." Again these aggregates preserve their structure intact, even after being heated to 700°, a temperature sufficient to invert both aragonite and μ -CaCO₃ to coarse-grained calcite; they then consist undoubtedly of calcite. These two lines of evidence point unmistakably to the inference that "vaterite" is spherulitic calcite containing water enmeshed among the fibres. This conclusion is corroborated by another line of evidence, as follows: Along with the typical spherical aggregates, there appeared in our experiments small numbers of aggregates of other shapes, all too small to be broken into fragments upon which optical measurements could be made, but the fibres of some of them are so nearly parallel that they extinguish simultaneously, and thus allow one to measure the maximum and minimum refractive index. These observed refractive indices range from those characteristic of calcite to those of "vaterite," though the aggregates themselves would have been called "vaterite."

We conceive then that these spherulites consist essentially of radiating prisms of calcite too fine to be resolved by the highest powers of the microscope; the individual calcite fibres are not all in actual contact—for, when crushed, the aggregates fall apart along radial lines—but are separated by very thin

*In one case the refractive indices of material precipitated from a much more alkaline solution were 1.585 and 1.455; practically all the spherulites yielded indications that the material about the center differed slightly from that in the outer layers.

†One would expect from the mode of preparation and state of the substance that it would contain potash which could not be removed by washing. Incidentally it may be observed that the fact of the retention by this material of as much as 4 per cent of free water is an additional example of the impossibility of distinguishing between combined and free water in fine-grained material by the loss of water on heating at any definite temperature.

films of the mother liquor in which the material was precipitated. The aggregate volume of these films, which are mainly water, is about 10 per cent of the whole, and causes a correspondingly smaller value of the apparent density and refractive index; this, together with the fact that well-crystallized calcite does not hold water in solid solution, leads to the conclusion that the water (and other impurities) is merely enmeshed in the very small interstices among the fibres making up the spherules or other aggregates. The conclusion that these aggregates are essentially calcite can not be considered as established absolutely, by reason of the fact that the separate fibres even are submicroscopic; but it accords best with what we know of the properties of these aggregates. There is one aspect, however, of their behavior for which we are unable to account; namely, that after some of this material had been shaken in a closed bottle for some weeks with water at 25°, it contained a small fraction of one per cent of aragonite needles, although the original aggregates contained no visible admixture of aragonite. The direct inference from this would be that these aggregates are unstable with respect to aragonite, and hence can hardly be calcite since aragonite is unstable with respect to calcite grains; but this behavior may be only apparently anomalous, for too much weight should not be attached to this in view of the circumstances that the aggregates are visibly not homogeneous initially and that the factors which determine the appearance of unstable forms are unknown.

2. *Ktypeite*.—The aggregated calcium carbonate of certain pisolites has been considered by Lacroix* to be a distinct form. The single definite difference from other forms upon which an argument for a new form rests is the positive character of interference figures obtained from thin sections of the pisolites. If we knew how the minute crystals of the pisolite were oriented we could better interpret the meaning of such interference figures. Lacroix does not consider this structure, but he does suggest that the optical phenomena of the sections are caused in part by strain. If we consider the only plausible theory yet advanced—that of Sorby†—for the structure of these pisolitic grains, then only sections passing near the center of a grain would give a definite interference figure in parallel light, and that figure would be positive. In convergent light no figure should be obtained from any section, but the positive figure produced by the objective might not be obscured.

Pisolite grains grown by the addition of plates of $\mu\text{-CaCO}_3$ to the surface would have positive optical character in thin

* A. Lacroix, *Compt. rend.*, cxxvi, 602, 1898.

† Sorby conceived that the pisolites from Carlsbad—one of Lacroix's localities—grow as if minute needles of aragonite were laid on tangential to the surface. *Quart. J. Geol. Soc.*, xxxv, 56, 1879.

section, and would have roughly the density observed by Lacroix (2.58–2.70), but the maximum double refraction of such sections would be 0.100 whereas Lacroix observed only 0.020. We may conclude, then, that until the precise nature of these pisolites is established the term “ktypeite” can have no definite significance.*

3. *Conchite*.—This alleged form, occurring in certain shells, has properties too close to those of aragonite for it to be definitely distinguishable,† and so needs no further consideration.

4. *Lublinite*.—There have been a number of papers on another alleged form, called lublinite; it occurs only as felt-like intergrowths of very small acicular crystals (not over 0.02^{mm} in breadth) with very oblique extinction. Quite recently, however, a critical study of the observed characteristics of this substance has been published by Quercigh,‡ who also reviews the previous papers dealing with lublinite. He has been able to observe in lublinite a perfect cleavage the direction of which is so related to the length of the needles that he considers the needles to be rhombohedral crystals greatly elongated parallel to a set of edges.§ The observed density and refractive indices are those of calcite within the limits of error—large in some cases—of the measurements. The crystals when heated to 450° do not recrystallize; when boiled with cobalt nitrate they give the reaction for calcite. Quercigh has, therefore, in our opinion, conclusively established that “lublinite” is identical with calcite.

5. “*Amorphous*” CaCO_3 .—One still encounters statements which imply that “amorphous” calcium carbonate is a distinct form in the same sense that the several crystalline forms are distinct; but all recent evidence bearing on this general question favors the view that the special properties of such “amorphous” material are dependent upon the extreme fineness of grain of the separate particles (as precipitated initially) and upon the mode in which these have come together to form the aggregates large enough to be examined under the microscope. Moreover it is, in the present instance, a subsidiary question whether these ultimate grains are really crystalline or are of the nature of supercooled liquids; even if crystalline, they are so very small, and hence the curvature of their surface is so great, that the forces acting at the surface may be large enough to mask the effects of the vectorial crystal forces within the particle. Again the extent of surface in proportion to their mass

* See also Vater's discussion, *Z. Kryst.*, xxxv, 149, 1902.

† R. Brauns, *Centr. Min. Geol.*, 1901, 134; H. Vater, *Z. Kryst.*, xxxv, 149, 1902.

‡ E. Quercigh, *Rivista Min. Crist. ital.*, xlv., 65–94, 1916; who gives references to all the previous papers.

§ The possibility of an organic origin should not be overlooked.

is so great that one may very plausibly imagine aggregates of them when dried to be made up of minute nuclei, each surrounded by a layer of material which is porous to some slight and variable extent; for which reason the aggregates as they are observed may appear to be amorphous, and may show properties differing from those of undoubted crystalline material. The centers of many of our crystalline aggregates of calcium carbonate had a lower refractive index than the surrounding material and were nearly or quite isotropic; these centers were, therefore, probably "amorphous" in the sense referred to above. The washed and dried gelatinous precipitates obtained by mixing concentrated solutions of CaCl_2 and Na_2CO_3 were isotropic and had an apparent refractive index when immersed in oil of 1.51–1.53.

It would lead too far to go fully into the question of the nature of these finest grains, a question which is discussed in all up-to-date books on colloids; but we shall give the merest outline of the reasoning in favor of the view at present most generally adopted. It has been shown by von Weimarn that, by appropriate variation of the conditions of precipitation, barium sulphate can be obtained in any size ranging *continuously* from well-formed crystals through microscopic and ultramicroscopic particles to particles which are too fine to be detected by the ultramicroscope; in other words, there is for barium sulphate—and therefore, in all probability, for other solid substances—a continuous gradation of many properties as we pass from undoubted crystals to "amorphous" material. Now the smaller the particle, the greater the surface force acting upon it, and this surface force increases in intensity more and more rapidly as the size of particle is reduced,* thereby masking the vectorial crystal forces, until it balances, and finally transcends them in importance. Aggregates of the smallest particles, therefore, have "amorphous" properties, though they may well be virtually crystalline since, when placed in a supersaturated solution of the substance, they can serve as nuclei about which crystallization takes place.

However this may ultimately prove to be, it is at the present time simplest to consider "amorphous" CaCO_3 , not as a separate and distinct form, but merely as a state of the substance whose properties in this state depend upon the size of the ultimate particles; and, since an actual sample of such material is not made up of particles of a single size, but contains a range of sizes in proportions depending upon its mode of production,

* A direct manifestation of this force is the fact that the solubility (as distinct from the rate of dissolution) of fine particles of a substance is greater than that of coarser particles—a phenomenon made use of when one allows a very fine precipitate to stand in order to obtain it in filterable form.

age and other factors, its properties are to that extent indefinite.

Calcium Carbonate Hexahydrate.

When calcium carbonate is precipitated at temperatures below about 20° , the product is partly or wholly hydrated; but the evidence in the literature* is inconclusive since many of the products analyzed were undoubtedly not homogeneous, but merely more or less accidental mixtures. Consequently it did not seem worth while to corroborate or refute all the statements made. The hexahydrate is the only one whose existence is undoubted, and the only one which we encountered in our experimental work.

We prepared this substance by slow precipitation, as already described, in presence of 2 grams KOH, the beaker being kept surrounded by ice; the product was filtered off rapidly on the pump, washed with alcohol and ether and dried by suction for a few minutes. The product obtained in this way is well crystallized and homogeneous and is pure hexahydrate, as the following analysis shows: 2 grams when heated to 150° evolved a vapor containing no CO_2 , yielding a residue of calcite (pure in so far as could be told from microscopic examination) which weighed 48.03 per cent† of the original, the theoretical proportion of CaCO_3 from $\text{CaCO}_3 \cdot 6\text{H}_2\text{O}$ being 48.08 per cent.

The hexahydrate prepared in this way consists of colorless monoclinic crystals, microscopic but well formed; in habit the crystals vary from tables parallel to the base—similar to those described and figured by Vetter—to stout prisms. Vetter's crystallographic measurements were confirmed, but his orientation of the crystals does not suit the prismatic habit of our preparations. The following orientation, in which the only forms are the prism and the three pinacoids, is satisfactory: $a:b:c = 1.02:1:1$; $2E = 72^{\circ} \pm 3^{\circ}$. The interior angle on the base between the front faces of the prism is $86^{\circ} \pm 1^{\circ}$; this true prism angle is 89° . The refractive indices are: $\alpha = 1.460$, $\beta = 1.535$, $\gamma = 1.545$. $\gamma \wedge c$ for yellow = $17^{\circ} \pm 2^{\circ}$ in the obtuse angle β , but there is noticeable dispersion of the bisectrices; optic plane parallel to the side pinacoid; $-2V = 38^{\circ}$.

Masses of crystals kept at room temperature under either ether, benzol, or clove oil pass within a few hours into mixtures of calcite and radiating or branching masses of rough crystals. These latter had refractive indices about $\alpha = 1.530$, $\gamma = 1.605$, if formed under ether, but the somewhat higher values,

* A summary of which may be found in Doelter's "Handbuch der Mineralchemie," I, 356.

† Cf. F. Vetter, Z. Kryst., xlviii, 71, 1911.

$\alpha = 1.54$, $\gamma = 1.63$, if formed under benzol; after two days these crystals had changed almost entirely to well-formed rhombs of calcite. In marked contrast to the rapid disappearance of this hydrate when in masses* is the preservation for months of separate well-formed crystals in clove oil under a microscope cover-glass; this is possibly analogous to the well-known fact that a perfect crystal of $\text{Na}_2\text{CO}_3 \cdot 10\text{H}_2\text{O}$ may be kept for a considerable time in the air, whereas imperfect crystals will rapidly effloresce. The hexahydrate changes rapidly at room temperature into calcite and water, and this process goes on in a few days† even at 0° showing thus that the hexahydrate also is unstable with respect to calcite at all temperatures above 0° . On the other hand, it is claimed‡ that crystals of hydrated carbonate have been found in wells and pumps. Accordingly this hydrate (or other hydrate) may conceivably be precipitated under natural conditions: viz., if it happen that water—in particular sea water—at a temperature of nearly 0° should become supersaturated with respect to CaCO_3 ; moreover if it does occur, it might readily pass undetected, for, by reason of its instability, examination of such material, if not undertaken immediately, would fail to disclose anything but calcite.

Before passing on to the consideration of the relations between the several forms, we give in Table I a summary statement of that portion of our experimental preparative work which we believe to be significant in relation to the previous discussion of the conditions of formation of the several forms of calcium carbonate. Most of these experiments were carried out in the way already described, but in a few cases (brought together in Table I b) special methods were employed; many of the experiments cited were repeated several times.

* This may be attributed to the presence in the crystal masses of interstitial water which, by its solvent action, would hasten the transformation.

† Cf. F. Vetter, *Z. Kryst.*, *xlvi*, 72, 1911. Really good crystals, however, persist for some weeks in contact with water at 0° .

‡ Pfeiffer (*Arch. Pharm.* [2], *xv*, 212) who considered them to be pentahydrate (cited from Thorpe's "Dictionary of Applied Chemistry," article on calcium carbonate).

TABLE I a.

Summary statement of experiments in which 100^{cc} each of 0.1 *M* K₂CO₃ and of 0.1 *M* CaCl₂ were dropped, under the special conditions noted below, into a beaker containing 800^{cc} of an aqueous solution as specified in the second column.

No. of expt.	Dissolved substance originally present grams	Temp. °C	Duration of pptn. hours	Character of ppt.*	Remarks.
1	—	2°	3	<i>C</i> + agg.	{ Rhombs of calcite. Agg. probably hexahydrate as the whole went to <i>C</i> in 1 hour at 100°.
2	—	25°	2	<i>C</i> + agg.	{ Rhombs of calcite. Agg. probably, in some cases certainly, μ . Proportions varied with rate of pptn.
3	—	55°	2½	<i>A</i> + μ + <i>C</i>	Mainly aragonite.
4	—	50°	3	μ + <i>A</i> + <i>C</i>	Mainly μ .
5	—	65°	3	<i>A</i> + μ	{ Needles of aragonite, with about 10% star-shaped crystals of μ .
6	—	85°	2	<i>A</i>	{ Needles of aragonite, pure except for an occasional admixture of a very little calcite.
7	2 g. KOH	2°	3	<i>H</i>	{ Repeated many times; only occasionally was calcite present.
8	“	18°	3	<i>C</i> or <i>H</i>	Generally calcite.
9	“	25°	3	“vaterite”	{ This gave the best samples of “vaterite”; but occasionally calcite appeared.
10	“	85°	3	<i>A</i>	In some experiments calcite appeared.
11	2 g. MgCl ₂ ·6H ₂ O	25°	2	agg.	{ Probably in part μ . Some extremely fine-grained Mg(OH ₂) was undoubtedly present in some of these pptes.

TABLE I a—Continued.

12	2 g. $\text{MgCl}_2 \cdot 6\text{H}_2\text{O}$	82°	3	A	{ Apparently a mixture of "vaterite" and μ with very fine material. In spite of many repetitions, no undoubted aragonite was ever observed.
13	2 g. $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$	25°	3	agg.	
14	1 g. $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$	25°	3	agg.	
15	2 g. NaCl	15°	2½	C + agg.	Aggregates probably in part hexahydrate.
16	30 g. NaCl	25°	3	C	{ A series of parallel rhombs of calcite enclosing a cerussite needle as vertical axis.
17	0.1 g. $\text{Pb}(\text{NO}_3)_2$	0°	3	C	
18	"	25°	3	A	
19	1.7 g. K_2SO_4	85°	3	A	{ The aragonite crystals had formed round nuclei of PbCO_3 . 0.7 g. K_2SO_4 in beaker—the remainder added with the carbonate to avoid an initial precipitation of calcium sulphate. The aragonite crystals in all cases had low refractive indices.
20	"	65°	3	A	
21	"	40°	3	C + μ + A	
22	"	30°	3	C + μ + A	Seeded with fine aragonite.
23	"	19°	3	A	

* C = calcite; A = aragonite; H = hexahydrate; agg. = aggregates.

TABLE 1b. Summary of precipitation experiments carried out as specified below.

In presence of solid calcium sulphate

- (24) Solid $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ shaken with $0.1\text{ }M\text{K}_2\text{CO}_3$ at 25° for 24 hours; the resulting ppte. proved to be calcite.
- (25) $1.5\text{ g. CaSO}_4 \cdot 2\text{H}_2\text{O} + 1.5\text{ g. K}_2\text{CO}_3 + 100^\circ\text{C H}_2\text{O}$ shaken for $1\frac{1}{2}$ hours at 25° ; ppte. calcite.
- (26) $1.5\text{ g. CaSO}_4 \cdot 2\text{H}_2\text{O} + 800^\circ\text{C H}_2\text{O}$ to which $100^\circ\text{C } 0.1\text{ }M\text{K}_2\text{CO}_3$ was dropped in $1\frac{1}{2}$ hours at
 (a) 25° ; ppte. calcite
 (b) 90° ; ppte. aragonite with admixture of sulphate.

In presence of ammonium bicarbonate at room temperature (approx. 22°C .)

In each case CO_2 was passed through the solution while the carbonate was added, so that no immediate precipitation of calcium carbonate took place. The precipitate was examined next day.

- (27) $35\text{ g. NaCl} + 2\text{ g. Am. Carb.} + 1.4\text{ g. CaCl}_2 \cdot 2\text{H}_2\text{O} + 1000\text{ g. H}_2\text{O}$; ppte. calcite + μ
- (28) As (27) + $2\text{ g. CaSO}_4 \cdot 2\text{H}_2\text{O}$; ppte. — calcite + μ
- (29) Artificial sea water as used by Linck; ppte. calcite + μ
 Each of these three precipitates contained enough of the μ -form to be mistaken for aragonite if the coloration test with $\text{Co}(\text{NO}_3)_2$ had been the only test made use of.

Miscellaneous

- (30) $2\text{ g. MgCO}_3 + 10\text{ g. CaCl}_2 \cdot 2\text{H}_2\text{O} + 100^\circ\text{C H}_2\text{O}$ shaken for $1\frac{1}{2}$ hours at
 (a) 24° ; ppte. calcite
 (b) 85° ; ppte. aragonite
- (31) $25^\circ\text{C } 0.1\text{ }M\text{K}_2\text{CO}_3 + 25^\circ\text{C } 0.1\text{ }M\text{CaCl}_2 + 100^\circ\text{C H}_2\text{O}$ after 2 hrs. at 20° gave a visible ppte. which, examined after 24 hrs., proved to be calcite.
- (32) On mixing equal volumes of $0.1\text{ }M\text{K}_2\text{CO}_3$ and $0.1\text{ }M\text{CaCl}_2$ directly a very fine indeterminable ppte. formed; the filtrate, after standing for a week at 20° deposited aggregates and a little μ
- (33) Saturated solutions of CaCl_2 and of K_2CO_3 when mixed gave a jelly of CaCO_3 .
- (34) $0.01\text{ }M\text{CaCl}_2 + 0.02\text{ }M\text{MgSO}_4$ mixed with $0.01\text{ }M\text{NaHCO}_3$ while CO_2 was passed; solution stirred continuously. Precipitate formed after stream of CO_2 was stopped; crystals of calcite, combination of (10 $\bar{1}$ 1) and another rhombohedron close to or exactly (70 $\bar{7}$ 1) — plane angle between edges = $15^\circ \pm 3^\circ$.

The Solubility of the Several Forms.

The solubility of any carbonate has a definite meaning only if the partial pressure of CO_2 above the solution at equilibrium is specified; in other words, we are dealing, not with a binary system, but with a ternary system $\text{R}_2\text{O} - \text{CO}_2 - \text{H}_2\text{O}$, and accordingly the concentration of all three components must be definite at equilibrium.* It follows, therefore, that the partial pressure of CO_2 must be carefully controlled and measured if the results are to be significant; thus, as an instance of the influence of CO_2 , a change in the proportion from 3 to 5 parts per 10000—an increase which may readily occur in the air of a laboratory within a very short time—alters the amount of calcium in a solution in equilibrium with calcite in the proportion of 63 to 75. In other words, the solubility of a carbonate in distilled water is indefinite unless the concentration of free CO_2 in the solution—or the partial pressure of CO_2 in the atmosphere in contact with the solution—is stated; and it is precisely the first increments in the amount of free CO_2 , which exert the greatest influence upon the solubility of a carbonate.

The existing data on the solubility of calcite have been collated and discussed in two previous papers,† to which the reader desirous of fuller information is referred. We now have concordant data extending over the whole range within which calcite is the stable phase in contact with water at ordinary temperatures; at 25° this range of partial pressures extends from an extremely small value (about 10^{-14} atm.), the point at which calcium hydroxide becomes the stable phase, to about 15 atm., at which point calcium bicarbonate is the stable phase. In the comparison of these solubilities there is a great advantage in considering the solubility-product constant‡ instead of the amount of carbonate dissolved; for, whereas the latter varies with the CO_2 pressure and with the concentration of other salts, the former is practically an invariable quantity for each solid phase at a given temperature§ and constitutes, therefore, a better basis of comparison. The solubility-product constant of calcite at the temperature t , for values of t between 0° and 30° , is given with sufficient accuracy by the expression $\log K'_c = 8.087 - 0.006t$; whence the solubility of calcite

* The same is true of sulphides with water.

† Johnston, J. Am. Chem. Soc., xxxvii, 2001, 1915; Johnston and Williamson, *ibid.*, xxxviii, May, 1916.

‡ The solubility product is $[\text{Ca}^{++}][\text{CO}_3^{--}]$, where $[\text{Ca}^{++}]$ and $[\text{CO}_3^{--}]$ represent the actual concentration of these ions in the solution; whenever the solution is in equilibrium with a definite solid phase (e. g. calcite) this product attains a constant value characteristic of the particular solid phase.

§ The influence of change of hydrostatic pressure is so small that it is negligible.

under a wide variety of conditions may be calculated with confidence.*

The relative solubility of calcite and aragonite has been the subject of several investigations, which finally have yielded reasonably satisfactory results. Kohlrausch and Rose† determined the specific conductance of conductivity water saturated with respect to aragonite (η_A) and to calcite (η_C), and Foote‡ made similar measurements in water previously saturated with CO_2 at 1 atm. From the ratio of these two specific conductances η_A/η_C the ratio of the respective solubility-product constants of aragonite (K_A) and calcite (K_C) is readily derived, subject only to the assumption that the presence of CO_2 above both solutions was identical; for, from the equations discussed in the previous paper§

$$\frac{K_A}{K_C} = \frac{[\text{Ca}^{++}]_A [\text{CO}_3^{--}]_A}{[\text{Ca}^{++}]_C [\text{CO}_3^{--}]_C} = \frac{[\text{Ca}^{++}]_A [\text{HCO}_3^-]_A^2}{[\text{Ca}^{++}]_C [\text{HCO}_3^-]_C^2} = \left(\frac{\eta_A}{\eta_C} \right)^3.$$

Foote also determined the ratio K_A/K_C by means of comparative experiments on the equilibrium $\text{CaCO}_3 + \text{K}_2\text{C}_2\text{O}_4 \rightleftharpoons \text{CaC}_2\text{O}_4 + \text{K}_2\text{CO}_3$; but the results at the higher temperatures are uncertain because, as Foote observed, a partial transformation of the aragonite to calcite occurred.|| Kendall¶ made very careful direct determinations of the solubility of calcite and aragonite in "freshly distilled water" which contained a "trace of CO_2 "; consequently the results can not be used as absolute values of the solubility, though the ratio derived from them is again significant provided that the partial pressure of CO_2 was the same in both series of measurements. In this case, if S_A and S_C are the respective solubilities (expressed in moles per liter) of aragonite and calcite

$$\frac{K_A}{K_C} = \frac{[\text{Ca}^{++}]_A [\text{HCO}_3^-]_A^2}{[\text{Ca}^{++}]_C [\text{HCO}_3^-]_C^2} = \frac{S_A \cdot \frac{S_A^2}{K}}{S_C \cdot \frac{S_C^2}{K}} = \left(\frac{S_A}{S_C} \right)^3.$$

Seyler and Lloyd** made a couple of experiments "at the temperature of the laboratory" in which they determined all

* For the methods of calculation see the papers already cited.

† Kohlrausch and Rose, *Z. physik. Chem.*, xii, 239, 1893; *ibid.*, xliv, 237, 1903.

‡ Foote, *ibid.*, xxxiii, 751, 1900.

§ Johnston, *J. Am. Chem. Soc.*, xxxvii, 2011, 1915. This particular relation was also derived by Foote (*loc. cit.*).

|| This implies that some grains of calcite were present in the material, for we have found that *pure* aragonite is stable in presence of water at 100° for some weeks and that this transformation is not appreciably accelerated in presence of fine-grained calcium oxalate.

¶ Kendall, *Phil. Mag.*, xxiii, 958, 1912.

** Seyler and Lloyd, *J. Chem. Soc.*, xcv, 1347, 1909.

the factors required for the direct calculation of the solubility-product constant; whence K_A/K_B is 1.35.

In none of the foregoing determinations were all the variables controlled with certainty; but quite recently Dr. R. C. Wells—to whom we wish to express our thanks for his kindness in enabling us to use his results, part of which are still unpublished*—has determined, in the laboratory of the U. S. Geological Survey, the solubility of both calcite and (artificial) aragonite in water in contact with an atmosphere containing a definite proportion of CO_2 (3.2 parts per 10000) over the temperature range 0° – 40° . His interpolated results are presented in the subjoined table, along with those of the authors cited

TABLE II.

The ratio of the Solubility-Product Constant of Aragonite (K_A) to that of Calcite (K_C), as derived from various sources.

Temp.	η_A/η_C	S_A/S_C	K_A/K_C	Remarks
0	1.22	—	1.8	{ Kohlrausch (1893); from the specific conductance (μ) of the saturated solution in "pure water."
18	1.19	—	1.7	
25	1.19	—	1.7	
34	1.18	—	1.6	
8	1.15	—	1.52	{ Foote (1900); from the specific conductance of the saturated solution in water saturated with CO_2 at 1 atm.
25	1.13	—	1.44	
41	1.12	—	1.40	
48	1.11	—	1.37	
25	—	—	1.35	{ Foote (1900); from the equilibrium $\text{CaCO}_3 + \text{K}_2\text{C}_2\text{O}_4 \rightleftharpoons \text{CaC}_2\text{O}_4 + \text{K}_2\text{CO}_3$.
49.7	—	—	1.36	
59	—	—	1.24	
18 ?	—	—	1.35	Seyler and Lloyd (1909).
25	—	1.064	1.21	Kendall (1912).
50	—	1.075	1.24	
100	—	1.069	1.22	
0	—	1.050	1.16	Wells (1915); interpolated from his observations.
10	—	1.053	1.17	
20	—	1.054	1.17	
30	—	1.060	1.19	
40	—	1.074	1.24	

* The results for calcite are given in J. Wash. Acad., v, 617, 1915.

above; and there is no doubt that of these Wells' figures are the most trustworthy, followed by those of Kendall, which agree with the former as closely as could be expected under the circumstances.

No attempt was made to determine the solubility of μ - CaCO_3 , as, since all of our products contained some admixture of calcite or aragonite, the results would have been illusory. But it is quite certain that, under ordinary laboratory conditions, it is less stable, and consequently more soluble, than either calcite or aragonite.

The Relative Stability of the Several Forms.

Calcite.—At ordinary pressure calcite is the stable form into which each of the others* ultimately transforms throughout the range of temperature hitherto investigated, i. e., at temperatures higher than 0° , below which the rate of reaction is so slow that it is difficult to determine the relation with any certainty. Calcite has at each temperature a definite dissociation pressure of CO_2 , which is about 0.1^{mm} at 500° and reaches one atmosphere at 900° † and is a measure of the tendency of the reaction $\text{CaCO}_3 \longrightarrow \text{CaO} + \text{CO}_2$ to progress. If the progress of this reaction is inhibited by a sufficient pressure of CO_2 , calcite goes over reversibly at 970° into α - CaCO_3 ,‡ the form of which is very similar to that of calcite; the latter melts at 1290° , the pressure of CO_2 required to inhibit dissociation being then about 110 atm.§

Aragonite.—Pure dry aragonite persists for an indefinite time at ordinary temperature; but this persistence is only an apparent stability conditioned by the extremely slow rate of transformation under these circumstances. This rate increases with temperature; the transformation is complete at 470° in a few minutes, at 425° in 90 minutes,§ whereas three hours heating at 400° induced no appreciable change in the aragonite. There is of course no transformation point in this region, the change being irreversible; such figures as are given above represent merely the temperatures at which the rate became appreciable under the conditions of experiment. The calcite which results when dry aragonite is heated retains the external form of the aragonite, but is easily distinguished by the refractive index; when a prism or aggregate of aragonite on inversion yields a single paramorphic crystal of calcite, the latter may extinguish parallel to the original extinction of the aragon-

* It is possible that aragonite containing other material in solid solution may not be unstable with respect to calcite; see p. 509 *postea*.

† See Johnston, J. Am. Chem. Soc., xxxii, 938, 1910; also Sosman, Hostetter and Merwin, J. Wash. Acad., v, 563, 1915.

‡ H. E. Boeke, Neues Jahrbuch, 1912, i, 91.

§ Sosman, Hostetter and Merwin, J. Wash. Acad., v, 563, 1915.

ite, but inclined extinction is also observed. Such relations indicate that transformation once started in a coherent mass of aragonite proceeds through the mass and that the orientation of the particles of aragonite encountered by the calcite as it grows does not have a determining influence on the orientation of the calcite.

In contact with water *pure* aragonite persists as such for an indefinite time at ordinary temperatures; but, on the other hand, in presence of calcite grains, it goes over into calcite at a rate depending mainly on the temperature. We were unable to detect any calcite amongst crystals of pure (artificial) aragonite which had been in contact with water at 100° for two weeks: the same material, after being in contact with water at room temperature for two years, contained some calcite, but the bulk of it still remained unchanged. This fact is opposed to statements of some previous investigators; the transformation which they observed is due without doubt to a lack of purity of their material. In order to ascertain the behavior of pure aragonite in contact with water at higher temperatures, a number of experiments were made, the results of which are summarized below; the mode of experiment was to place 0.2 g. aragonite, together with the amount of water noted in the first column, in a gold crucible contained within a leak-proof steel bomb* (the volume of which was 70^{cc}) which was then heated in an electric furnace to the desired temperature.

This table shows that the rate is not rapid—from a laboratory standpoint—unless the temperature is higher than 300°; and that the rate of transformation of pure aragonite to calcite is greater in presence of water. The results at 340° are not quite consistent, presumably by reason of the presence of a little calcite; but since, as noted above, this lowest temperature has no especial significance, it was not deemed worth while to endeavor to secure thoroughly consistent results. The table indicates moreover that aragonite yields calcite rhombs by transformation when liquid water is present, but inverts to paramorphs in water vapor as in air.

The evidence which we have adduced demonstrates conclusively that pure† aragonite is unstable with respect to calcite at all temperatures above 0° under atmospheric pressure.‡ Whether it has a region of real stability at higher pressures or at temperatures below 0° is an open question about which little can be said. It may be mentioned, however, that the

* For details see Morey, J. Am. Chem. Soc., xxxvi, 217, 1914.

† With respect to impure aragonite, see *postea* p. 509.

‡ The conclusions reached by Vaubel relative to the constitution of calcite and aragonite (J. prakt. Chem., lxxvi, 366, 1912), are merely fanciful and have no foundation in fact.

TABLE III.

Summary statement of experiments on the transformation of aragonite to calcite in presence of water (liquid or vapor).

Amt. of water grams.	Temp. C.	Duration of heating hours*	State of water	Remarks
10	190	24	liquid	No change.
10	270	24	liquid	"
10	280	48	liquid	"
1	300	24	vapor	"
1	300	48	vapor	"
10	337	24	liquid	Changed to calcite rhombs.
10	340	24	liquid	No change.
10	345	24	liquid	Changed to calcite rhombs.
10	345	24	vapor (?)	{ Changed to calcite paramorphs; we had reason to believe that the bomb had leaked slightly in this experiment.
1	350	24	vapor	{ Changed in part to calcite paramorphs.
10	400	24	vapor	Changed to calcite paramorphs.
1	400	24	vapor	" " "
10	410	24	vapor	" " "

* Of this time from 3 to 4 hours would be required for the attainment of the final temperature; the cooling took place always in less than 5 minutes.

ratio of the solubility of aragonite to calcite is, according to Wells' results, diminishing towards unity as the temperature diminishes, and would, if the rate of change remain constant, become unity in the neighborhood of -100° ; consequently, on this basis, there would be in this region a transition point below which aragonite would be the stable phase under atmospheric pressure.*

$\mu\text{-CaCO}_3$.—Under ordinary conditions this substance is unstable with respect to both calcite and aragonite, and goes over into one or other of these forms at a rate depending upon the conditions—into calcite in 5 minutes at 410° .

$\text{CaCO}_3 \cdot 6\text{H}_2\text{O}$ is likewise unstable with respect to calcite at temperatures above 0° , and is transformed at a rate depending upon the conditions; the relations below 0° are unknown.

The Heat of Transformation of Aragonite to Calcite.

Closely related to the question of the stability relations of aragonite is that of its heat of transformation to calcite; this we shall now discuss briefly, as part of the evidence, being in Russian, is not generally available.

Favre and Silbermann state that aragonite on going over to calcite gives out 20 calories per gram;† Le Chatelier,‡ on the other hand, claims an absorption of 3 cal.; but little reliance can be placed upon either of these figures, representing as they do a difference between two quantities a hundredfold larger and determined with an accuracy not better than one per cent of their values. Boeke§ endeavored to estimate it at 470° by a differential method capable of detecting a sudden heat change (e. g. such as accompanies the melting of a salt) of 0.5 cal. per gram; but he was unable to detect any heat effect. We have tried similar experiments in which the sensitiveness was more than 10 times as great as Boeke employed, but with the same result; but this negative result does not necessarily imply that the heat of transformation is of the order of 0.1 cal. per gram or less, because the transition actually is not a sudden one, but is spread out over a considerable temperature interval. The most recent publication dealing with the question is that

* An analogous case of a reversible transformation is benzilortho-carboxylic acid, studied by Soch (J. Phys. Chem., ii, 364, 1898). The white α -form is stable below about 65° , the yellow β -form between 65° and 132° ; yet on heating the substance to 180° and cooling very suddenly both white and yellow crystals are formed. Indeed the proportion of α in the liquid increase with rising temperature, which indicates that at some temperature between 65 and 132° the heat of transformation $\alpha \rightarrow \beta$ is zero.

† Cited from Abegg's Handbuch II, ii, 155.

‡ Le Chatelier, Comp. rend., cxvi, 390, 1893.

§ Boeke, Z. anorg. Chem., 1, 246, 1906.

of Lashchenko,* according to whom there is an evolution of 27 cal. per gram; but this estimate is based upon a misapprehension of his results. For his method could yield only the total heat evolved when either aragonite or calcite cooled from 465° to 20° , and the difference therefore would represent merely the difference in heat capacity over this temperature range; but his observed difference is far greater than that deduced from the most trustworthy series of experiments† (viz. 1.8 cal. per gram) and his high value is due probably to some dissociation of the aragonite with the production of free lime.

Altogether then this heat of transformation is probably small, but its sign is unknown. Incidentally it may be remarked that, on the basis of the values of specific heat cited above, the heat of transformation per gram will be at 470° about 1.8 cal. algebraically less than it is at 20° ; so that, if the heat effect is small and positive at 20° , it may at some higher temperature become zero and reverse its sign.

The Precipitation of Unstable Forms.

In taking up this important question let us consider first the course of events when solutions of, say, sodium sulphate and barium chloride are gradually added to a large volume of water, ultimately producing barium sulphate, a substance which, so far as we know, appears only in a single crystalline form. The concentration of the barium ion $[\text{Ba}^{++}]$ and of sulphate ion $[\text{SO}_4^-]$ increase, and hence their product $[\text{Ba}^{++}][\text{SO}_4^-]$ gradually increases, but as soon as this product has attained a value K —viz., the characteristic solubility-product constant appropriate to the temperature—precipitation begins provided that nuclei are present; but if nuclei are not present, some degree of supersaturation‡ will be attained before precipitation begins. Now the size of the precipitated particles depends upon the degree of supersaturation at the moment of precipitation, the particles tending to be smaller (and more numerous) the greater the supersaturation,§ and consequently

* Lashchenko, J. Russ. Phys. Chem. Soc., xliii, 793, 1911. We are indebted to Dr. E. W. Posnjak, who translated portions of this article for us.

† Lindner, Sitzber. physik. medicin. Ges., Erlangen, xxiv, 217, 1902.

‡ The degree of supersaturation required to induce the separation of nuclei of any particular substance depends upon conditions, e. g., upon the mode of stirring and the other substances present in the liquid. (See L. C. de Copet, Ann. chim. phys., x, 457, 1907; S. W. Young, J. Am. Chem. Soc., xxxiii, 148, 1911; S. W. Young and R. J. Cross, *ibid.*, 1375, 1911. There is therefore no definite curve of supersaturation, as was postulated by Miers and Isaac (Proc. Roy. Soc., London, A, lxxix, 322, 1907; F. Isaac, J. Chem. Soc., xciii, 384, 1908; Miers and Isaac, *ibid.*, xciii, 927, 1908; B. M. Jones, *ibid.*, xciii, 1739, 1908.)

§ Cf. Table I, experiment No. 33, where the momentary supersaturation was so great that a jelly resulted.

upon the concentration, rate and mode of mixing of the constituent solutions, as well as upon the solubility of the substance in the medium in which it is being precipitated. This constitutes the reason for using diffusion processes (as a means of securing very slow mixing and thus keeping down the degree of supersaturation) for the preparation of good crystals of sparingly soluble substances,* and likewise for the occurrence in nature of large crystals of substances which in the laboratory appear only as very small crystals or even as "amorphous" material.

Now the precipitation of a substance, such as calcium carbonate, which appears in unstable forms, is a more complicated question, though, as we believe, the above principles still hold. When the product $[Ca^{++}][CO_3^-]$ has attained the value K_C characteristic of calcite, the latter will begin to precipitate if there be nuclei of itself or of some isomorphous substance; but if nuclei are absent, the product $[Ca^{++}][CO_3^-]$ may increase until it has exceeded the value characteristic of one or other, or of all, of the unstable forms and consequently the precipitation of any of the three forms is now possible. The form which actually precipitates is, in the absence of nuclei isomorphous with any of these forms, determined presumably by whichever nucleus first separates; but as to which this is likely to be under given conditions, nothing definite can be stated at the present time. It may be remarked merely that, if we suppose that all of the types of pre-nuclei are present simultaneously in the liquid, the question as to which appears is a question of the relative probability of the configurations of the several nuclei, and hence is not likely to be elucidated until more is known about the real structure, and mode of growth, of crystals. It is obvious, therefore, that the appearance of any form is a matter of chance, in so far as we can tell, since it depends upon factors which we cannot even specify. Nevertheless there are some indications of proximate causes which we shall point out, though they cannot yet be interpreted unambiguously.

One essential condition is that the solution must be virtually supersaturated with respect to the more stable forms before the less stable forms can possibly separate out; this implies moreover, that unstable forms are likely to appear only if the ratio of solubilities is not far removed from unity.† Now in

* See Johnston, J. Am. Chem. Soc., xxxvi, 16, 1914. It may be mentioned that soluble substances, such as NaCl, which usually crystallize well, may be obtained as very fine-grained "amorphous" material by precipitating it rapidly in a medium in which it is very sparingly soluble.

† At a given temperature this ratio of solubilities of any two forms of the same substance is affected little, if any, by change of solvent; consequently one may plausibly infer that in an endeavor to precipitate unstable forms of any substance, one should choose a medium in which the substance is not

our experiments, carried out as described previously (p. 480), considerable supersaturation occurred invariably; in general no precipitate was observed until from 20 to 50° of each solution had been added, the actual amount depending mainly on the substance initially present in the beaker. This amount of supersaturation was unquestionably greatest in those experiments in which the less stable products appeared, particularly so when the solutions were alkaline, whence we infer that the presence of alkali favors supersaturation in the case of CaCO_3 . This action of the alkali* may be plausibly interpreted in two ways:

(1) that it serves as a peptising agent, just as it does with many colloids, keeping down the size of the particles;

(2) there is ground for the belief—though it cannot be regarded as established—that calcite appears more readily when the concentration of bicarbonate ($[\text{HCO}_3^-]$) is higher; on which basis any factor such as free alkali (i. e. $[\text{OH}^-]$) which diminishes $[\text{HCO}_3^-]$ will be prejudicial to the formation of calcite, and consequently promote the appearance of the less stable forms.† Incidentally it may be remarked that, if this belief be correct, the point at which the solution is absolutely neutral will possess no special significance in connection with the appearance of one or the other form, because the acidity or alkalinity of the solution is not a direct measure of the concentration of HCO_3^- ; in other words, in this case (and probably also in analogous cases, sulphides for instance), the point of absolute neutrality is not a definite limit beyond which either form may not appear.

However this may ultimately prove to be, our work leads us to believe that, *in the absence of nuclei* ensuring the precipitation of calcite or aragonite, the initial precipitate at temperatures ranging from about 15° up to 70°, or even higher, is the μ -form, alone or mixed with the other forms. On this basis one may account for the precipitation of aragonite at temperatures upwards of 70° on the plausible supposition that at such temperatures the rate of transformation of the initially-formed very fine particles of these unstable forms has become so great that they cease to appear, the result being that the next in order of stability precipitates.

too soluble. This may be correlated with the fact that soluble substances are seldom, if ever, encountered as unstable forms, except when the solubilities of these two forms are exceedingly close together (as in the immediate neighborhood of the transition point).

* In other cases, on the other hand, alkalinity seems to favor the precipitation of the stable form; see Allen, Crenshaw, and Merwin, this Journal, xxxiv, 341, 1912; *ibid.*, xxxviii, 393, 1914, on the forms of ZnS , HgS and FeS_2 .

† Nevertheless "vaterite," which we believe to be a special habit of calcite, appears most readily in alkaline solution.

One other point remains to be noticed—namely, the consequences of the fact that the solubility of a substance depends upon the fineness of grain, that a solution saturated with respect to fine grains is supersaturated with respect to larger grains and conversely; this phenomenon is made use of constantly as a means of coarsening the grain of fine precipitates and so rendering them filterable. This difference in solubility is not marked until the grains become very fine; nevertheless, in the case of a substance capable of existence in more than one form, the solubility of a large crystal of the less stable form may be less than that of very fine particles of the more stable form. Consequently, especially since the difference in solubility of crystals of aragonite and calcite is so small, it may be that large crystals of aragonite are really stable with respect to very small particles of calcite. On this basis one can account for the fact that aragonite free from calcite may be kept for a long time in contact with water at 100° without undergoing any change to calcite; for the minute calcite particles which would tend to appear are unstable with respect to the crystalline aragonite.

This problem will require further and more extended investigation before more definite statements as to the rationale of the appearance of unstable forms can be made. It is recognized that the experimental basis of the foregoing remarks is less secure than one could wish; yet any hypothesis which aids in the interpretation and correlation of phenomena is better than none at all, and is especially necessary in such a puzzling problem as this, where we are trying to ascertain what factors *actually* determine the apparently accidental appearance of one or other of the unstable forms.

Some Applications to the Natural Minerals.

Up to this point we have considered in the main the preparation and properties of the three distinct crystalline forms of calcium carbonate in the pure state; but a discussion of their geologic relationships must take into account the effect of possible impurities (held mechanically or in solid solution) and of porosity upon their properties. As to the presence of impurities and their effects upon the crystals, there are few data which can be correlated; and a determination, no matter how carefully it is made, of a single property of crystals of unknown purity is of little value as a contribution towards ascertaining the genetic relationships or to determinative mineralogy. If the slight value of even a carefully determined single characteristic of a mineral, as compared to the high value of two or more characteristics determined upon the same specimen, were

more generally appreciated and acted upon, a critical review of the behavior and properties of a mineral would be more readily prepared and would help greatly to settle many questions still outstanding.

*Natural calcite** is in many occurrences very pure, and its physical properties are well known; but little is known as to the effect of impurities upon its properties. Foote and Bradley† analyzed specimens of calcite which had deposited in open spaces on dolomite, and found close to 1 per cent MgCO_3 as a probable maximal limiting amount in solid solution under the various conditions of formation of these specimens. Observations of the refractive index of the calcite in dolomitic limestones lead us to the belief that under some conditions more than 1 per cent MgCO_3 may be present; moreover, there is a greater likelihood of equilibrium in the limestones themselves than in the deposits in open spaces, so that this is not in conflict with the observations of Foote and Bradley. In this connection we remark that the *stable* solid phase in contact with solutions containing magnesium is calcite only so long as the concentration of magnesium does not exceed a certain limiting value, beyond which it is dolomite;‡ but whether this limiting concentration of magnesium carbonate—which, moreover, will vary with the temperature—is near that now present in the sea is a question about which nothing has yet been definitely ascertained.§

Natural aragonite is usually not pure; all available analyses indicate that it contains significant amounts of admixed substance, commonly the carbonate of lead, strontium or zinc,|| present presumably in solid solution. The aragonite found in the sea may contain calcium sulphate; we have identified, separated, and analyzed about a gram of the minute separate needles of aragonite occurring in the muds of the shoal waters of the

* A discussion of some of the agencies which influence the deposition of calcium carbonate is given in another paper now in course of publication in *J. Geology*.

† Foote and Bradley, this *Journal*, xxxvii, 339, 1914. The crystals analyzed were clear, so that there is here little question that the magnesium was present as carbonate, even though the CO_2 was not determined directly. But it is to be noted that in fine-grained material the magnesium might in some cases be present as hydroxide, as it is in fact in the outer layer of Portland cement which has set in sea-water.

‡ Just as, in presence of sodium, with gaylussite ($\text{CaCO}_3 \cdot \text{Na}_2\text{CO}_3 \cdot 5\text{H}_2\text{O}$) and pirssonite ($\text{CaCO}_3 \cdot \text{Na}_2\text{CO}_3 \cdot 2\text{H}_2\text{O}$). See Wegscheider and Walter, *Monatsh.*, xxviii, 633, 1907.

§ The latest work along this line is that of Spangenberg (*Z. Kryst.*, lii, 529, 1913) who succeeded in producing undoubted dolomite at a temperature of $180\text{--}200^\circ$ and a pressure of CO_2 of about 50 atm.

|| G. M. Butler (*Econ. Geol.*, viii, 8, 1913) describes a variety containing nearly 10 per cent Zn. This fact accords with the idea that there is a form of ZnCO_3 isomorphous with aragonite (see Griffiths and Dreyfus, *Chem. News*, liv, 67, 1886).

Bahamas,* and found that they contain about 0.7 per cent of sulphate reckoned as CaSO_4 —a quantity of precisely the same order as we found in samples of aragonite precipitated from solutions containing sulphate at ordinary temperature. The fact of the solid solution is significant for two reasons: that it probably determined (1) the precipitation as aragonite; (2) the preservation of aragonite as such.

(1) There is reason for believing that aragonite does not form in nature except (a) through organic agencies (e. g. in shells); (b) by deposition from hot springs; (c) when an isomorphous carbonate is present to serve as nucleus; (d) and, apparently, by chemical precipitation in saline waters, even at ordinary temperature, under certain circumstances which we are unable to specify except that the presence of sulphate appears to be requisite. It is, however, not possible to state in what way these factors favor the formation of aragonite, nor can we be sure that the above comprise all the important factors.

(2) Pure aragonite in presence of water transforms slowly into calcite,† so that the preservation of aragonite in any but recent geological formations‡ may depend upon its having been kept dry. In the older rocks fossil shells of types such that they were presumably aragonite originally, now consist of calcite. Now the solubility of pure aragonite is not much greater than that of calcite, and this difference would be diminished by the presence of other material in solid solution in the aragonite; it is conceivable, therefore, that such impure aragonite should be really stable in contact with the natural waters§ in which it formed. On this basis, then, it is plausible (though not yet established) that natural aragonite containing other substances in solid solution should be practically stable under certain conditions. Incidentally, it may be remarked that the

* The sample (No. 177) was furnished to us by Dr. T. W. Vaughan, who has recorded a mechanical analysis of it in the 1914 Year Book of the Carnegie Institution of Washington.

† An interesting example of this is given in a very recent paper by W. Watanabe (Beiträge Min. Japan No. 5, 237, 1915). Cones have formed (and are still forming, depositing at the rate of about 44 grams daily) at the mouth of a series of springs or geysers, the temperature of the water being about 94° ; these cones have formed in less than a year, yet, though the outer and more recent portions are aragonite, the inner and older part has changed to calcite.

‡ For example, the aragonite associated with zeolites in the basalt of Table Mountain, Colorado, described by Cross and Hillebrand (U. S. G. S., Bull. 20, 39, 1885), may have been formed in early Tertiary time.

§ This implies that these waters contained sufficient of the admixed substance that it was in equilibrium as between the liquid and solid solution. Such impure aragonite would cease to be permanently stable in contact with pure water; thus it may be that chemically precipitated aragonite, which apparently persists under some circumstances in saline waters, is soon transformed to calcite when exposed to the action of meteoric waters.

transformation of aragonite to calcite is accompanied by a 10 per cent increase of volume, so that rocks which initially contained any considerable proportion of aragonite that subsequently transformed to calcite, should show evidences of this fact.

μ - CaCO_3 .—There have not been enough geological observations to enable one to discriminate between aragonite and μ - CaCO_3 in recent deposits, so that the evidence does not warrant a definite conclusion as to the occurrence in nature of the μ -form: but our laboratory experiments lead us to believe that it is formed in many places, but soon changes to calcite or aragonite. That it has not been recognized is due to two facts, namely: that, in presence of water, it persists presumably only for a period measurable in days or weeks since the minute crystals formed in the laboratory transform in a short time, and that the color tests do not enable one to differentiate it from aragonite.

We have collated some of the characteristic properties of the three forms of pure calcium carbonate, and what little is known of the range of variation of the properties exhibited by the natural minerals; the results are presented in Table 4, which shows at a glance the resemblances between them.

Recapitulation.

Under ordinary conditions, calcium carbonate appears in three crystalline anhydrous forms, viz., as calcite, aragonite, and a form which we have designated μ - CaCO_3 . The other reputed forms, including "vaterite" and "amorphous" CaCO_3 , are not definite forms; their divergent properties are due mainly to differences in size of grain, and mode of aggregation.

Of these three established forms, calcite is, at ordinary pressure, the stable one at all temperatures from 0° (or lower) up to 970° , at which temperature it inverts reversibly to α - CaCO_3 ; under these conditions aragonite and the μ -form are always unstable with respect to calcite, though there is an indication that aragonite has a stable field of existence at about -100° or lower. Under all ordinary conditions, therefore, pure aragonite tends to go over into calcite; in how far it actually does so depends upon the rate of this process under the particular circumstances. There is therefore no definite transition point; the interval required for the transformation at 100° in presence of water and calcite is measured in days, and for its inversion at or about 400° is measured in hours. By reason of this instability, one cannot specify the factor or factors which determine the precipitation of CaCO_3 , as aragonite; indeed, its appearance would seem to be a matter of

TABLE IV. Properties of the forms of CaCO_3 .

Form	Crystal system	Optical character	n		Density d	Remarks
			max.	min.		
Calcite	Hex.	—	1.658	1.486	2.71	d by Goldschmidt, Z. Kryst. 13, 635, 1888. contains varying amounts of enmeshed water and alkali.
			1.658	1.486	2.713	
			1.585 to 1.64	1.455 to 1.47	2.51 and greater	
			1.682	1.527	2.88	
Aragonite	Orth.	—	1.673 to 1.650	1.520 to 1.510		large range in n and d .
$\mu\text{—CaCO}_3$	Hex.	+	1.550	1.550	2.54	Density determined on aggregates.
$\text{CaCO}_3 \cdot 6\text{H}_2\text{O}$	Mon.	—	1.545	1.460	1.75	d from Vetter, Z. Kryst. 48, 56 (1911).

chance,—in other words, it depends upon factors which cannot be controlled at the present time. In so far as we have been able to ascertain, natural aragonite is formed (a) through organic agencies, (b) by deposition from hot springs, (c) when an isomorphous carbonate is present to serve as nucleus; (d) in salt waters containing sulphate even at ordinary temperatures. Pure aragonite can persist as such only when dry; but aragonite containing other substances in solid solution may thereby be enabled to persist in presence of certain solutions. There are indications that the μ -form often occurs as an intermediate step in the precipitation of the other forms; but it soon transforms in presence of water, a fact which, combined with the fact that it cannot be differentiated from aragonite by means of the usual color tests, is responsible for the circumstance that it has not been recognized as occurring in nature.

The properties of these three forms, and of the hexahydrate $\text{CaCO}_3 \cdot 6\text{H}_2\text{O}$ (which, moreover, is also unstable with respect to calcite even at 0°) are described; some of the characteristic properties have been collated in Table 4. The several forms can be differentiated from one another by optical, crystallographic, and chemical tests, by observation of density and of the stability of the material when heated; but it is not safe to trust to a single one of these tests, especially with fine-grained material, as the result may be ambiguous. Much of the work in the past is vitiated by the fact that the criteria employed were insufficient to differentiate one form from another; and thus many of the statements to be found in the literature require revision. In conclusion, we might point out that a determination, no matter how carefully carried out, of a single property of a substance is of much less value than two or more characteristics of the same specimen: and make a plea for the determination on an analyzed specimen of as many diverse properties as possible, for it is only in this way that it will be possible to coördinate the various observations in a satisfactory way. As an illustration of this point, one cannot state the manner in which the properties of so well-defined and common a mineral as calcite vary with the presence of other substances in it, in spite of the enormous number of isolated observations which have been made; and it is obvious that such a coördination, once established, would save an immense amount of labor thereafter.

Geophysical Laboratory,
Carnegie Institution of Washington,
Washington, D. C., March 27, 1916.

ART. XXXIV.—*Fundamental Distinctions Special to the Process of Transmission of Terrestrial Radiation by the Atmosphere, and the Value which is Obtained for the Coefficient of Transmission when these are Considered*; by FRANK W. VERY.

IN finding the transmission of terrestrial radiation by the atmosphere, I have hitherto assumed that it is unnecessary to measure more than the zenithal radiation, for the following reason: If we consider the radiation to a limited area of the sky from an instrument having a very small surface, normal to the direction of the rays, the radiation falls off as the pointing departs from the zenith and is practically zero close to the horizon. Hence some have supposed that a complex summation of the radiation by zones is needed in order to get the actual "sky radiation." But in nature, the absorption is exerted in a comparatively shallow layer of air close to the surface and the radiator is not a minute area, or almost a point, but is an indefinitely extended surface faced by a parallel and closely juxtaposed absorbent layer. It is, therefore, only necessary to consider the transference between two layers in a normal direction, that is, vertically.

In proof that this is so, we have only to try a still more direct experiment by making the moon our distant radiant source, after eliminating that part of its rays (both visible and invisible) which is simply reflected solar radiation, and getting the transmission of the true lunar emission through an entire atmosphere. On trial, the result demonstrates that the zenithal observation with a radiator of limited surface, and radiating to a limited angular area, is the one to be used; and that the zonal integration which gives a smaller apparent transmission and one which does not represent a natural fact, is at fault, because the details with which the summation is concerned are purely those of a laboratory experiment, while the conditions in nature are entirely different.

The fallacy just noted may have arisen from a common practice of measuring what is sometimes called "nocturnal radiation," or the radiation of a thermometer-bulb to either a part or the whole of the night sky. As an instrumental method, this is perfectly legitimate, but the result should not be confounded with the radiation of a widely extended surface of the earth to space, which is the true terrestrial nocturnal radiation.

In this Journal for April, 1913, I gave a curve of apparent sky temperature obtained by a thermopile of limited aperture (fig. 2, p. 383). Here the readings were entirely similar to those which might be obtained by a nocturnal radiation ther-

monometer, also of limited aperture; and the curve might be summed zonally, were it not that such a summation could have no useful significance. The really important fact is that given by the *lowest* reading, or that in the direction of the zenith; and since there appears to be an impression among some leading astrophysicists that the day sky ought to give *positive* deflections, I will call attention to the fact that a clear sky never gives any other than negative readings, whether by day or by night; and that on the date of the above-mentioned curve—a hot, sunshiny day in July—the apparent temperature of the sky was *zero Centigrade*.

It is not yet sufficiently recognized that the radiation which proceeds from the earth's surface, or at least that portion of it which is absorbed by the atmosphere, does not continue very long as rectilinear propagation in the original directions, but becomes almost immediately involved in the meshes of molecular kinetics, and thenceforth is handed on in a *vertical* direction in connection with those processes by which the normal upward change of air pressure is maintained.

At my present station, which is not far from Boston, skies good enough for measurements of air transmission are rather rare in winter. This may possibly be due to the neighborhood of the ocean, since, when the water is considerably warmer than the land, the diffusion of water vapor from the ocean into colder air over the land may very likely produce a thin mist in certain layers. It is extraordinary how a scarcely perceptible mist will take down the sky transmission, and, indeed, my experiments on the transmission of radiation from a boiling radiator at a distance of about 100 meters suggest that it is not necessary for the atmospheric water to be actually precipitated in liquid form in order that it shall do this. It is enough that saturation be imminent, because this condition conduces to the formation of highly absorbent hydrols, even before actual precipitation has begun. This will be made evident when my long-continued observations on these radiations under every possible condition of atmospheric moisture shall have been published.

In summer the land is warmer than the ocean on sunny days, and any vapor coming from the ocean to air over the land is in a fair way to recede from the saturation point. Hence there are plenty of days in summer when transmission measures can be made. From long experience at the Allegheny Observatory, I can say that, notwithstanding Pittsburgh smoke which sadly dims the visible rays, nevertheless, transmission of terrestrial radiation is but little affected by the smoke, unless saturation is so near that the carbon particles serve as condensation nuclei; while the absence of the ocean is very likely

the reason why it was easier to find suitable occasions for such measures in winter at Allegheny than it is at Westwood. Out of twenty-one observations of sky radiation made here on six days in winter between Jan. 20 and Feb. 3, 1909,* only one was good enough to give a genuine *air* transmission; but all of the nineteen summer measures on three days in July were good, and many more as good could have been given.

When the measures of terrestrial radiation, obtained from zenith-sky observations on these suitable occasions, are plotted with the surface pressures of water vapor as abscissæ, they are well represented by the curve which Mr. Anders Ångström has published.† My measures were all made several years before Mr. Ångström's paper appeared, and by an entirely different method. They are, therefore, completely independent. This being so, and the agreement between our separate experimental work being very nearly perfect, it may well be asked how it is that such diverse conclusions in regard to transmission can be drawn from what are practically the same data; for, whereas I have maintained for many years that the atmosphere in middle latitudes transmits, on the average, about 40 per cent of radiation,‡ the observed values varying between 26 per cent in summer and 58 per cent in winter,§ Mr. Ångström, on the other hand, states his belief|| “that the transmission for clear sky seldom is greater than 25 per cent and seldom is less than about 5 per cent.” If this statement referred to those imperfect skies which, however much they may delight the farmer praying for rain, are the bane of astrophysics, no fault could be found; but on referring to the accompanying text, this reading is seen to be inadmissible. The discrepancy arises from the aforesaid diverse modes of reduction, but the smaller values have also been supported by further erroneous arguments.

In his note¶ Mr. Ångström illustrates by assuming a surface temperature of 283° Abs. C. which “should, if no atmospheric radiation existed [that is to say, if the atmosphere were absolutely transmissive], radiate to space $0.490 \frac{\text{cal.}}{\text{cm}^2 \text{ min.}}$.”

The “effective” sky radiation is then taken as -0.15 , which

* Published in this Journal for April, 1913, pp. 379-380.

† Astrophysical Journal, vol. xxxvii, p. 319, fig. 2, June, 1913. It is a pleasure to note one more point on which we coincide. This is Mr. Ångström's recognition that dry dust alone, suspended in air, has almost no influence on the transmission of terrestrial radiation, confirming results reached during my work at Allegheny.

‡ See Astrophysical Journal, vol. xxxiv, p. 375, December, 1911, and also earlier papers.

§ See also Science, N. S., vol. xl, p. 420, September 18, 1914.

|| Astrophysical Journal, vol. xxxviii, p. 200, September, 1913.

¶ Op. cit., p. 198.

I endorse, at least as a good average summer value; but the "conclusion that about 0.07 gr. cal. or only about 14 per cent of the radiation from the earth's surface will escape the absorbing atmosphere and go out to space"* does not follow. For, let it be noted, the observed radiation of 0.15 to the sky *is* the radiation immediately to space from the surface of the earth. The restriction that "a part of the observed nocturnal radiation is not transmitted entirely through the atmosphere, but merely to its colder layers,"† can not be admitted.

The "nocturnal radiation" which is "observed" gets through to space. The statement made that, because certain observers had given the value of $0.12 \frac{\text{gr. cal.}}{\text{cm}^2 \text{ min.}}$ for "atmospheric radiation"

at a height of 3000^m, we must therefore "consider about 0.06 gr. cal. [assumed to be the *mean* "atmospheric radiation" of an air layer 3000^m deep] of the nocturnal radiation as intercepted by colder layers of the lower atmosphere"‡ is certainly incorrect. Actually, $.49 - .15 = .34$ gr. cal., or between five and six times as much, has been intercepted! The "colder layers" of the atmosphere could be obliterated completely without altering the transmission of *terrestrial* radiation appreciably, for it is the lower warm and moist layers in contact with the surface which do the work. The amount specified by Ångström could be easily intercepted in the first 100 meters of air (this is known from the experiments with the distant radiator), and almost all of the radiation which the atmosphere is capable of absorbing will be taken out long before the level of 3000^m is reached, because, after the readily absorbable rays have been struck out, the passage through subsequent layers adds little to the absorption.

A layer of air extending from the surface up to 3000^m is assumed by Mr. Ångström to be "the effective radiating layer of the atmosphere." But the lower layers of the atmosphere are prevented from radiating directly to space on account of the absorption of their peculiar radiations by higher layers. Still less can air raised some hundreds or thousands of meters above the surface radiate downward to the ground to any appreciable extent, because the lower layers have greater absorbent power for the air's own peculiar radiation, and besides, the lower layers are apt to be hotter than those above. Moreover, all of the lower layers of air lose their heat to some extent in other ways than by immediate radiation. For example, a good deal of the hotter air is cooled by simply being mixed with colder air, being transported as wind to distant localities where the temperature is lower. Not that

* Astrophysical Journal, vol. xxxviii, p. 200, September, 1913.

† Op. cit., p. 199.

‡ Op. cit., p. 199.

this constitutes a final disposal of the heat. The thermal energy is still imprisoned. Its only way of escape is through the gradual processes of internal radiation which are found to be most fundamental and at the bottom of all of those physical properties which we call "atmospheric."*

If any layer of the atmosphere deserves to be called "the effective radiating layer," it is the isothermal layer, where convection being no longer potent, the heat obtained by absorption of the incoming solar rays must be radiated back to space, since it can not accumulate indefinitely. There is no evidence whatever of Ångström's effective radiant layer of the atmosphere at 3000 meters. On the other hand, the peculiarly potent radiation-function of the isothermal layer of the atmosphere has been repeatedly pointed out by me.†

Here is the source of the fallacy: The $0.15 \frac{\text{cal.}}{\text{cm}^2 \text{ min.}}$ of observed terrestrial radiation goes out scot free, and the transmission of terrestrial radiation is truly 30 per cent in the given case. Most of the remaining 70 per cent is not directly transmitted to the "colder layers" at 3000^m, there to be absorbed; and still less does any portion of the 30 per cent linger there, as Ångström supposes; but the 70 per cent is mainly absorbed within a few hundred meters of the surface, at most, and is thereafter indirectly transmitted to space through the step-by-step process of alternating gaseous absorption and reradiation which is described in my treatise on "Atmospheric Radiation," published in 1900. Included in the 70 per cent, there may be an absorption of 2 or 3 per cent which is special to ozone in elevated regions of the air.‡ Unless the 70 per cent absorbed by the air were also "transmitted" in the end, though in its own slow way and through a complex of radiation, convection, penetration, aqueous condensation and evaporation, etc., which can scarcely be attacked in any other way than by the methods of thermodynamics, the earth's surface would all the time be getting hotter, since it receives fresh accessions of heat from the sun's rays every day. Some portions of this atmospheric thermal energy are radiated directly to space by cloud sur-

* In confirmation of this assertion, I will merely note that the first differences of the radiant potential of the air in a vertical section through the atmosphere form a curve which agrees precisely with the curve of the vertical distribution of density, proving that it is the radiation between the air molecules which governs the kinetic mechanism of the gaseous mass.

† Compare "Atmospheric Radiation," Bulletin G, U. S. Weather Bureau, 1900, p. 123; "The Solar Constant," Weather Bureau Pub. No. 254, 1901, p. 25; Astrophysical Journal, vol. xxxiv, p. 386, December, 1911; and especially the paper: "Sky Radiation and the Isothermal Layer," this Journal, vol. xxxv, pp. 369-388, April, 1913.

‡ See my quantitative measurements of this absorption, Science, N. S., vol. xl, p. 421, September 18, 1914.

faces; but the isothermal layer in its more attenuated parts, where at last the air molecules are free to radiate directly to space, is the final dispenser of this accumulated energy.

We reserve the term "transmission of terrestrial radiation" for that portion of the thermal energy at the earth's solid or liquid surface which, being transformed into radiation of such wave-lengths that the air cannot absorb it, escapes directly to space. That this is what happens to the radiation emitted from the earth to the sky is made certain by the following facts: In my paper* on "The Probable Range of Temperature on the Moon" I gave 48 per cent as the transmission, or 52 per cent as the atmospheric absorption of the extreme infrared radiation emitted by the moon (from winter measures). The earth radiates at a lower temperature than the moon, because the earth reflects the larger part of the sun's rays, falling on it,† and therefore somewhat longer wave-lengths preponderate in its spectrum. These fall outside the region of greatest aqueous absorption, and are therefore *more* freely transmitted than lunar radiation whose maximum falls within the great Ξ band of aqueous vapor. Hence, on the nights in question, a larger percentage of terrestrial radiation must have been escaping than the percentage of lunar radiation then undoubtedly entering through the same absorbent atmosphere; and it is not at all exceptional that I obtain from winter measures of terrestrial radiation the value given in my paper in Science on "The Transmission of Terrestrial Radiation by the Earth's Atmosphere in Summer and in Winter," namely, an absorption of 42 per cent, which is comparable with the value given by Dr. Nils Ekholm for absorption of terrestrial radiation by atmospheric aqueous vapor in more northern lands, and is fully confirmed by the same, notwithstanding Mr. Ångström's opinion. "In Sweden the absorption amounts to about 45 per cent and only in the polar regions does it fall below 30 per cent," says Dr. Ekholm;‡ that is, transmissions of 55 to 70 per cent are the rule in these northern lands.

In describing his method which presupposes radiation to an entire hemisphere, Mr. Ångström says:§ "It must always be regarded as a dangerous approximation to calculate the radiation to the whole sky from the radiation to a limited part, assuming a certain standard distribution of radiation." This may also be true as regards radiation to the sky in other direc-

* Astrophysical Journal for November and December, 1898; cf. p. 275.

† See my determination of "The Earth's Albedo," *Astronomische Nachrichten*, Nr. 4696, November, 1913; and a more elaborate, or definitive determination in *A. N.*, Nr. 4819-20.

‡ *Om Naturens Värmehushållning*, K. Vetenskapsakademiens Årsbok 1914, p. 314.

§ Astrophysical Journal, vol. xxxvii, p. 315, June, 1913.

tions than the vertical, where special reduction to the zenith is required; but nevertheless, with a clear sky, my method of observing the zenithal sky gives nearly the same observed radiation as Ångström's method, as has been shown already. The differences appear only in the further treatment of the observations by diverse and irreconcilable theories. The necessity for my mode of treating the data arises from the fact that the absorption of terrestrial radiation takes place in a layer of air of small depth immediately above the surface. Thus we may regard earth and "sky" as two widely extended parallel surfaces in close proximity; and if we assume them to be "black bodies," we can compute their effective radiations by Stefan's Law. Hence, on the supposition of a normal transference between the two, the zenithal observation of sky radiation virtually integrates the natural process and gives the rate at which heat is lost, rendering unnecessary any complicated summarization by zones. Nor can a small thermometer bulb, for whose radiation a zonal summation would be appropriate, represent the radiation of an extended surface. But each element of horizontal surface may be considered as in radiant exchange with the vertical air column of equal section situated directly over it.

The hemispherical summation of sunlight diffused by the sky upon a given point and the radiation from an instrument of limited area to the sky follow different laws. For if we consider the case of a zenithal sun, it is evident that, within a given solid angle, the reflected skylight comes from greater depths of air according as the direction approaches the horizon, and the light therefore increases in intensity at the low altitudes; but the earth's radiation to the sky, as represented by a circumscribed measuring instrument, is more absorbed in directions near the horizon than at the zenith, and therefore earth radiation (as thus measured) proceeding outward diminishes just where the incoming solar radiation, diffused by the sky, increases. Thus in the summation for the hemisphere, skylight from the hemisphere bears a larger ratio to skylight for a given solid angle of high altitude, than terrestrial radiation to the hemisphere bears to the same solid angle at the zenith. This is the reason why Ångström, who measures the radiation to a hemisphere, always gets a positive value for radiation received from the sun-illuminated sky in the daytime, but a negative value for the night sky, while I find the zenithal value always negative, whether by day or by night. The apparent discrepancy is just what we ought to expect. I have not access to the observations of Homén, who also found negative sky radiation both by day and by night, but if his method at all resembles mine, Ångström's conclusion "that the observations

of Homén were made under conditions that must be regarded as exceptional" is not necessarily justified.

The mean value of 14 per cent which Ångström derives for the transmission of terrestrial radiation by the atmosphere from considerations which I have shown above to be based on fallacies, is further advocated by him because it "is not far from that derived by Abbot and Fowle from the measurements on the absorptive power of the water-vapor"; but the apparent support of these measurements is also fallacious, since, as I proved conclusively in "Atmospheric Radiation" (p. 99), diluted water-vapor, that is, a given depth of water spread in the form of vapor through a very large depth of air, transmits much more freely than the same amount of aqueous vapor in concentrated form and equal equivalent depth. "The same quantity of water in the form of steam takes out about 15 per cent, and distributed as atmospheric vapor only one-half of 1 per cent." I have already pointed out the inadequacy of the theory of aqueous absorption held by these observers.*

Much vagueness and misconception would be removed if it were realized that there is a fundamental distinction between the transmission of a large part of the solar radiation by the atmosphere, and that of terrestrial radiation by the same atmosphere. Diffuse selective reflection enters very largely into the skylight problem and the process is conducted with the speed of light, which for atmospheric distances is practically instantaneous; but the terrestrial radiation which does not immediately escape to space, becomes air radiation and passes from molecule to molecule by a very large number of alternations and thus remains a long time in the medium. This has been shown in my "Note on Atmospheric Radiation," † and also more elaborately in a computation of the flux of volume energy, which appears to constitute air radiation, through the height of the atmosphere, in my paper: "On the Solar Constant," ‡ where it is shown that "the thermal energy which gives air pressure is maintained by the internal radiation between the air molecules."

Certain theorists have attached a great importance to changes in atmospheric carbon dioxide as a climatic factor. It is true that this gas has a strong absorption band at 14.7μ , which looks very imposing when plotted on a percentage scale of absorption; but when it is recognized that there is only a small part of the total terrestrial radiation included within the limits of this band, it may be seen that its effect is relatively insignificant. Ozone also, in spite of some large claims by Mr.

* See *Astrophysical Journal*, vol. xxxiv, p. 373.

† This *Journal*, vol. xxxiv, p. 533, December, 1912.

‡ *Ibid.*, vol. xxxix, p. 204, *et seq.*, February, 1915.

Ångström, is of quite minor importance. He assigns to "the remaining 0.09 gr. cal. which probably are transmitted through the lower absorbing layers" (meaning by this the entire remnant of nocturnal radiation, since, of the original 0.15 of this illustration, 0.06 gr. cal. are supposed by him to be stopped at 3000 m.) a further absorption by "ozone in the higher and colder strata of the atmosphere," amounting in winter to 50 per cent, and on the average to 20 per cent. The ozone band between 9 and 10 μ , discovered by Professor Kuut Ångström, sometimes exerts an absorption of 50 per cent in winter, but within the limits of the band only. It is not correct to apply this value of the percentage of absorption, within a limited range of wave-length, to the entire remnant left from aqueous absorption which extends through many times this range. This is not the first time that similar elementary considerations have been pointed out, but since they are frequently overlooked as in the present instance, it is necessary to emphasize them. My measures show that, in winter, between 3.00 and 3.72 per cent of the entire remnant of the spectrum beyond great Ξ , left after aqueous absorption, may be absorbed by ozone, and much less in summer, the remaining radiation, over 96 per cent, falling outside the limits of the ozone band. Compared with water vapor and its products, the hydrols, all other atmospheric absorbents are nearly negligible.

Taking the extremes of the range of terrestrial radiation ($R = \frac{\text{gr. cal.}}{\text{cm}^2 \text{ min.}}$) as influenced by aqueous vapor (pressure of vapor in mm. = a), we have :

Ångström	$a = 3.50$ to 4.50 ,	$R = 0.198$
"	$a = 11.90$ " 13.24 ,	$R = 0.146$
Very (Winter)	$a = 0.63$ " 2.39 ,	$R = 0.222$
" (Summer)	$a = 9.14$ " 12.67 ,	$R = 0.149$
Homén	$R = 0.22$ " 0.13 .	

These results being in good agreement, and since the afore-said lunar observation definitely confirms the larger values of the transmission of terrestrial radiation deduced for middle latitudes by the method advocated in this paper, we may conclude that with the clearest skies and in middle latitudes, transmissions of about 26 per cent are common in summer and upwards of 58 per cent in winter.

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ART. XXXV.—*A New Longirostral Mastodon from Nebraska, Tetrabelodon osborni, sp. nov.*; by ERWIN H. BARBOUR.

THE Nebraska State Museum was enriched during the field season of 1915 by an abundant and varied mammalian fauna from the fossil fields of Northern Nebraska. Much of this has an added interest because new. However, the collection of proboscidean bones seems to challenge first attention. Considerable *Tetrabelodon* material was secured, notably several fine jaws, two of which are probably new, one undoubtedly so. The latter, or the Boyd County *Tetrabelodon*, constitutes the basis of this paper.

The spring and summer of 1915 were characterized by unusual precipitation. Running water gullied a pasture belonging to Mr. Z. T. Long, 7 miles north and 2 miles east of Bristow, Nebraska, and exposed a *Tetrabelodon*. After making extensive excavations in the hope of securing this specimen, Mr. Long recognized the futility of the undertaking, promptly buried the exposed bones, and set up a barricade to ward off herds. Appreciating the scientific value of the specimen, he had notice sent, late in June, to the University of Nebraska. Many similar skeletons have been found in the State but practically all of them have been destroyed before notice was given.

In company with Mr. C. Harold Eaton, the writer visited Bristow at once, and in less than a fortnight, the skeleton of a new *Tetrabelodon*, practically complete, was secured. The skeleton was exposed on a sloping hillside in channel gravels composed of three or four feet of very coarse, line pebbles underlain by five or six feet of fine sand. The deposit is of Pliocene age equivalent to the Snake River of Cherry County, and the lower Devil's Gulch beds of Brown County. For convenience we shall call these the Bristow beds.

The skull and mandible, though checked and fragile, were finely preserved, and one fore-limb had all of its elements, from scapula to manus inclusive, in position. The skull, mandible and hyoids, pelvis, scapulæ, and numerous ribs were close to the surface. Consequently they were checked to the extreme degree, and rootlets had found their way into the bones. It required extreme care in collecting to save this specimen. Certain bones, at a depth of three to seven feet, were harder and less checked.

Without waiting for the preparation of the skull and skeletal parts, it seems expedient to figure and briefly describe the mandible.

For this new proboscidean, we wish to propose the name *Tetrabelodon osborni*, in recognition of Dr. Henry Fairfield Osborn. The peculiarities of the skull promise to be so great that eventually this specimen must be assigned to a new genus.

In this *Tetrabelodon* a unique adaptation presents itself, and a new principle seems to be involved, namely, the use of the mandible and the mandibular tusks for work and defense. There is a suggestion in the protruding mandible and its strong, recurved tusks, that they may have functioned as a sort of shovel in digging and tearing up roots, aquatic plants, and the like. However this may be, the inferior tusks are well developed and modified, while the superior, though heavy, are short and seemingly useless.

The mandible of *Tetrabelodon osborni* seems to differ in many essentials from other longirostral forms found in the State. Such differences can scarcely be attributed to age, sex, or individual variation, and must be counted specific. The mandible is long and very strong, the rami widely divergent, the angle thin and reflected, the symphyseal portion relatively short, noticeably broadened and somewhat upturned at the tip. The lingual groove is moderately deep behind but shallow in front, and the walls converge from 5 inches posteriorly to 3 inches anteriorly and blend at once into the flattened, broadened tip. The ascending ramus is very oblique, the condyle large, the coronoid low, and the sigmoid notch shallow and straight. The length and leverage of this great jaw seems to call for broad, erect, ascending rami. Just back of the molars the jaw is thin, in front very thick. Anteriorly, the

FIG. 1.

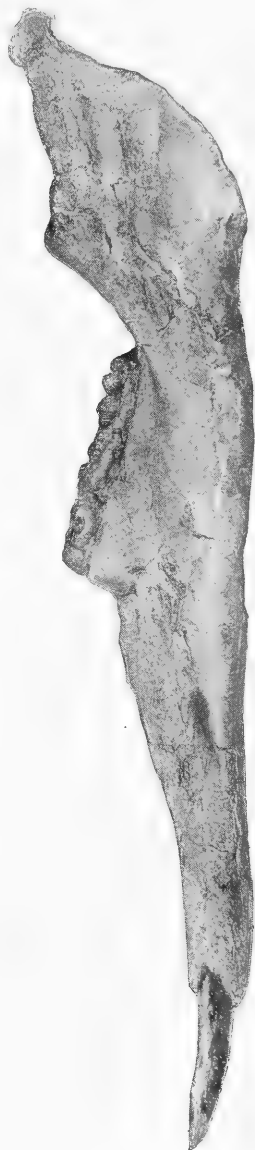
FIG. 1. Mandible of *Tetrabelodon osborni*. $\times 1/10$.

FIG. 2.

FIG. 2. Mandible of *Tetrabelodon osborni*, crown view. $\times 1/10$.

symphysis becomes broader than thick, unlike other forms in the Nebraska State Museum. The elongated, mental foramen is close upon the inferior border. The inner alveolar border extends as a ridge well to the condyle.

The jaw is that of an adult, but not an aged individual. Molars five and six are present and are fairly well worn. The fifth molar has three, while the sixth has four, transverse crests and a large heel. This heel, which is as well developed as the fifth ridge in *Mastodon americanus*, would have developed into a fifth crest by continued wear. Along the middle line of the tooth rise the accessory cones, regularly and mostly singly. Accordingly, the tooth is made up of alternating major and minor ridges. Excepting these alternating cones, the tooth is not unlike the sixth molar of *Mastodon americanus*. The cingulum is strong and broad. The sixth molar is $7\frac{1}{2}$ inches (190^{mm}) long, 3 inches (76^{mm}) wide through the cingulum, and has a grinding surface of 2 inches. Where the teeth are broken, the dentine shows distinct decussation. The pattern of the worn crown is not distinctly trefoiled as are many of our Tetrabelodons. The teeth slant backward and inward. The low stature of the creature, 7 feet, and the long jaw, 5 feet, made it easy to reach the ground with the lower tusks. The inferior tusks are long and strong. They are imbedded the length of the symphysis and are about as long as the superior tusks, and protrude, at most, about 10 inches out of the jaw. They are $1\frac{1}{2}$ inches (38^{mm}) thick and 2 inches (51^{mm}) broad, and are produced into a dull edge laterally.

The jaw and its tusks protruded more than 2 feet (610^{mm}) beyond the skull. It was a grotesque head on a grotesque body. The skull, still in plaster "cinches," is relatively short, about two-thirds that of the mandible, and the upper tusks very short and stout.

Fortunately, both of the upper tusks are perfect and in place in the skull. They curve downward and outward and are produced to a distinct point and are somewhat flattened on the inner side. They are about 4 inches (102^{mm}) in diameter and very short, for scarcely more than 16 or 18 inches (407 to 457^{mm}) protrude beyond the incisive sheath, and still less beyond the flesh in life.

In association with this specimen were teeth of three other individuals of unlike species, and the bones and teeth of horse (*Protohippus* and *Hipparion*), rhinoceros, camel, and rodent (*Dipoides tortus*).

The articulated forelimb indicates an animal little more than 7 feet in height, half that of a large mammoth. The vertebræ seem large out of all proportion, being equal in size to those of the mammoth. This Tetrabelodon was short-legged, broad-

FIG. 3.



FIG. 3. Mandible of *Tetrabelodon osborni* from below. $\times 1/10$.

hipped, heavy-bodied, and perhaps semi-aquatic in habit. Its body must have dragged close to the ground, not unlike *Teleoceras fossiger*, the short-legged rhinoceros.

Measurements of Mandible.

	Inches	Milli- meters
Length from condyle to tip of tusk	60	1522
“ exclusive of tusk	53	1346
Width across condyles, over all	25½	647
Length of symphysis	19	483
Width “ “ at its tip	6	152
“ “ “ mental foramen	5	127
Thickness of jaw at 5th molar	8	203
“ “ “ back of 6th molar	5½	140
“ “ “ at tip	3	76
“ “ “ just back of mental foramen	6	152

Measurements of Limb Bones.

	Inches	Milli- meters
Scapula, along mesoscapular line	26	660
Length of humerus	26	660
Trochlear, width	8	203
Diameter across head and tubercle	9	229
Length of radius	22	559
Ulna, over all	24	610
Length of femur, about	30	762
Diameter of head	5	127
Across pelvis	60	1522

Measurements of Skull.

(Still in plaster “cinches.”)

	Inches	Millimeters
Occipital condyles to tip of tusk, about.	52	1320
Length of skull exclusive of tusks	36 to 38	915 to 965
Width of skull, about	28	710
Depth of skull, about	20	508

The bones of the forelimbs are short and disproportionately heavy, while those of the hind limbs are short and relatively light. The scapula varies noticeably from the general proboscidean type. The prescapula seems to be reduced to a remnant in the lower half and to a mere ridge in the upper. The postscapula and mesoscapula are correspondingly developed. The mesoscapula extends as a stout, erect ridge to the suprascapular border. The humerus, radius and ulna, carpals, and phalangeals are noticeably short and extremely heavy.

It is apparent that other material is to be expected in this pit and since the owner encourages further exploration, work will be resumed, if possible, during the season of 1916. Within a few months, all parts of the new *Tetrabelodon* will be prepared, whereupon photographs and descriptions, entering more into detail, will be published.

The specimen figured and described herein is from the collections of Hon. Charles H. Morrill and Mr. Hector Maiben,

FIG. 4.

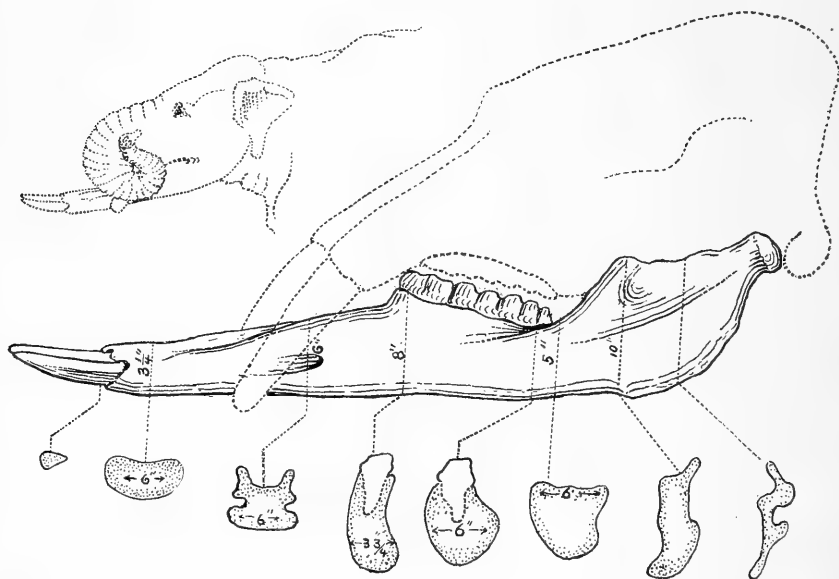


FIG. 4. Skull and mandible of *Tetrabelodon osborni*. $\times 1/15$. The skull is still in plaster "cinches." Below are shown sections of tusk and mandible. Above, a conjectural restoration of the head. "5" should read $5\frac{1}{2}$ ".

Patrons of Paleontology, The University of Nebraska, field season 1915.

Since the above was written, the plaster "cinches" have been removed from the palatine and occipital regions, and from most of the left side of the skull, well to its dome. In brief, the skull is that of an unelephant-like elephant. Barring innumerable cracks, the skull seems anatomically perfect, and is rich in morphological suggestions. It seems impressively simple and lacks the specialization of the later forms. The dome is unexpectedly low; the occiput flat, though rounding

above; the pit small. All sutures are obliterated save those bounding the malar. The basicranial elements, the palatine roof, and the incisive sheaths are not deflected but are in the same plane. The occipital condyles are as large as those of the mammoth, which they resemble. The cranial walls are strikingly thin, and the air-cells greatly reduced both in size and number. They do not extend to all parts of the skull as they do in mammoths and modern elephants. They are wanting altogether in all portions of the zygomatic arch. The malar portion of the zygoma is relatively slender and weak; the maxillary portion heavy and strong; the postnasal aperture is disproportionately small. The temporal or squamosal process is very broad, heavy and strong, the condylar portion predominating. It exceeds that of the mammoth itself. The condylar articulation is upon the anterior border. The postglenoid portion is a thin, sharp ridge pendant from the flattened occiput. The glenoid fossa is located at the base of the postglenoid ridge and runs into the external auditory meatus, which is located close upon the basioccipital. It is interesting to note the progressive migration of the meatus from a central position in our early proboscideans to one at the circumference in modern forms, and to observe the gradual arching over and union of the squamosal ridge and the postglenoid, as in the Indian elephant.

The infraorbital foramen is encased in a sheath twice as long as that of *E. columbi*. The incisive sheaths are very short. The tusks though short are impressive because of their size and shape. They are 4 inches in diameter but expand noticeably toward the middle of the tusk and then contract to the pointed tip. On the under side they are produced to a blunt ridge: so a section is an acute, inverted ovoid. The enamel band is uncommonly broad, $2\frac{1}{2}$ inches. In the Nebraska *Tetrabelodons* the maxillo-premaxillary suture seems to run in a nearly straight line paralleling the axis of the tusk and does not curve under as in *E. indicus*.

The University of Nebraska,
Lincoln, Nebraska, March 15, 1916.

ART. XXXVI.—*Two Caudal Vertebrae of a Sauropodous Dinosaur Exhibiting a Pathological Lesion*; by ROY L. MOODIE.

THE assistance which paleontology may render students of disease is instanced by the following discussion of a pathological lesion involving two caudal vertebrae of a sauropodous dinosaur from the Como Beds of Wyoming. The specimen is the property of the Kansas University Museum and I am indebted to Mr. H. T. Martin for the privilege of describing it.

So far as the present writer is aware, the occurrence of pathological processes in fossil vertebrates have been described only as incidents in connection with the descriptive anatomy of the forms. Abel* has, to be sure, given a short discussion of evidences of disease in fossilized bones. Fossil bones exhibiting these interesting features of ancient disease are not commonly seen in our collections. Yet such as do occur should be described so that those students of medicine who are interested in the origin of disease may have the opportunity to examine the evidence afforded by paleontology. Broken ribs, fractured limb bones, and injured vertebrae, a part or all of which show evidence of disease, may occasionally be seen and should be described.

An examination of the figure reveals a lesion not unfamiliar to students of modern pathology. It has the appearance of a spongy growth surrounding the intervertebral articular surfaces, and involving the spinous processes of these two caudal vertebrae. The normal form of the vertebrae is well known to readers of this journal and the large amount of pathological growth is evident. The mass resembles closely the tumor-like masses of oak trees. It entirely encircles the vertebrae and has involved fully half of the two bones. All evidence of separate structure is obliterated and the vascular canal of the chevron has been filled by the bony matter, and the chevron has been pushed far out of its normal position.

The specimen has a length of 26.5^{cm} and a weight of 5.1 kg. The circumference of the normal articular surface is 27^{cm}, and the same measurements around the middle of the tumor-like mass is 38.5^{cm}. The surface of the lesion is rather deeply pitted, and the mass is asymmetrical, having attained greater dimensions on one side than on the other.

The enlargement is somewhat suggestive of the lesion of chronic osteomyelitis. It may be a callous growth due possibly to a fracture of the caudal vertebrae; or it may be a bone

* Abel, O., 1912, *Paleobiologie*, pp. 91-95.

tumor. Its nature is of course uncertain, but it is an interesting thing that in the Comanchic pathological processes should have produced results which are to all appearances the same as occur today.

My purpose in describing this unusual lesion in this place is to call the attention of paleontologists to the desirability of

FIG. 1.



describing such of these objects as come to their attention in order that their possible value may be available for those who are interested in the study of the nature and origin of disease. This will be entirely new matter for the student of modern pathology and may be of great service. Then too it will broaden the scope and usefulness of paleontology.

Department of Anatomy,
University of Illinois, Chicago.

ART. XXXVII.—*The Growth of Crystals Under External Pressure*; by STEPHEN TABER.

THE question whether it is possible for growing crystals to exert a linear pressure is of such great interest and importance to geologists that it is surprising the problem has received so little attention. Jean Lavalle, in 1853, appears to have been the first to assert that crystals do exert such a force.* He observed that crystals were pushed upward during their growth. This, however, was denied by Kopp, who, upon placing crystals of alum colored with a small amount of chrome alum in a solution of plain alum and allowing them to grow, noticed that no material was deposited on the under side of the colored crystals. He states that he was never able to observe anything tending to confirm the view that a crystal can raise itself in order to grow also on the side on which it rests.† Since that time several investigators have published their conclusions but they have reached no general agreement. It is not necessary to review here the literature bearing on the subject, a very complete bibliography of which has already been published by Dr. K. Andrée.‡

In 1905 Becker and Day published an account of their very interesting and suggestive experiments.§ Using alum, they found it possible "in a saturated solution of constant temperature to grow clear crystals a centimeter in diameter which would raise a weight of a kilogram through a distance of several tenths of a millimeter. The crystal was placed upon a piece of plate glass in a beaker containing saturated solution of the same material, and loaded as desired. Knowing the weight raised, it appeared an exceedingly simple matter to determine the force required, since it was only necessary to ascertain the actual area of contact between the weight and the crystal. Here, however, an unexpected difficulty was encountered."|| The under side of the crystal where it rests on the plate glass, instead of being plane consists of a terraced cavity so that the bearing surface is only a narrow rim around the outer edge of the crystal. The exact measurement of this area of contact is very difficult and uncertain, and, therefore, it is hard to estimate the force per unit area exerted by the crystal. However,

* Compt. Rend., vol. xxxvi, p. 493, 1853.

† Kopp, H., Über die Bildung von Krystallen mit Kernen, Ann. Chem. Pharm., vol. xciv, p. 124, 1855.

‡ Die geologische Bedeutung des Wachstumsdrucks kristallisierender Substanzen, Geologische Rundschau, vol. iii, pp. 7-15, 1912.

§ Becker, G. F., and Day, A. L., The Linear Force of Growing Crystals, Proc. Washington Academy of Sciences, vol. vii, pp. 283-288, 1905.

|| Ibid., pp. 285-286.

Becker and Day state that "It was at once evident that it amounted to many pounds per square inch, and as observations multiplied, it became reasonably certain that it is actually of the same order of magnitude as the ascertained resistance which the crystals offered to crushing stresses."*

Important as these conclusions are, the paper by Becker and Day did not attract the immediate and general attention that it deserved, possibly because it did not have as wide a distribution as it would have had if printed elsewhere than in the proceedings of a local society. And while it opened a wide field for further research no one seems to have taken advantage of it.

In 1913 two German investigators, Bruhns and Mecklenburg, published a paper† in which they claim to have repeated the experiments of Becker and Day with negative results, and they criticise the description of these experiments, stating that it is not so accurate and full as one might expect in the case of such a striking phenomenon.‡ Their own paper is certainly not open to this criticism, for they describe in the greatest detail the manner in which their experiments were conducted.

It is not necessary to repeat here all the details of their experiments, but one detail is important as it evidently explains why Bruhns and Mecklenburg obtained results differing from those described by the two American scientists. In a crystallizing dish containing a saturated solution of alum the German investigators placed *two crystals of alum* of approximately the same size and weight; *one of these was left uncovered, while the other was covered* with a glass plate on which was placed a weight of one kilogram.§ From time to time the crystals were removed from the solution and after being carefully dried, were measured and weighed. The experiments were repeated several times, the results obtained being tabulated. An inspection of the tables shows that the height of the unloaded crystals increased, while that of the loaded crystals remained practically the same. Both increased in weight, but the unloaded crystals gained nearly twice as much as the loaded ones.

Bruhns and Mecklenburg go further and state that the weight resting on the covered crystal plays, as such, no important rôle; the essential thing being the circumstance that the upper face of the crystal is protected from the addition of further substance.|| In proof of this statement they describe another experiment in which four crystals of alum were placed

* Ibid., pp. 286-287.

† Bruhns, W. and Mecklenburg, Werner, Über die sogenannte "Kristallisationskraft," 6th Jahresbericht d. Niedersächsischen geologischen Vereins, pp. 92-115, 1913.

‡ Ibid., p. 96.

§ Ibid., p. 99.

|| Ibid., p. 100.

in a saturated solution; two of the crystals being covered by light glass plates while the other two were left uncovered. The crystals were measured from time to time and the results tabulated as before. These results are in every way similar to those obtained in the previous experiments.

In the fall of 1914 the writer of the present paper began a series of experiments with the object of determining whether it is possible for growing crystals to exert a linear pressure, and if so, the conditions under which the pressure is developed; for, obviously it is not always in evidence, or such contradictory results as those cited above would never have been obtained by careful investigators. Some of the more important experiments conducted by the writer are described in the following pages, and the conclusions that may be drawn from them are also discussed. All of the questions growing out of this work have not been solved, but it was thought best to put on record such facts as have been established in order that others might aid in carrying on the investigation.

Before going into details it is advisable that the problem be clearly defined, for some observers have wrongly attributed to crystal growth certain phenomena that are without question due to other processes. Reference is here made to that class of phenomena which are due to chemical or physical changes taking place with increases of volume in a closed and insufficient space. The present investigation has been limited to those evidences of mechanical pressure accompanying crystallization that are not *obviously* to be explained in this way.

The writer began his investigations by growing crystals of alum in crystallizing dishes placed in desiccators containing sulphuric acid, care being taken to follow all of the precautions observed by Bruhns and Mecklenburg. The experiments were conducted in a room where the temperature fluctuations were not more than 5°C . Some of the crystallizing dishes contained both loaded and unloaded crystals, while other dishes contained only loaded crystals; otherwise the conditions were the same for all of the tests. At first the results were rather confusing, some crystals lifting their load several tenths of a millimeter, while others showed no increase in height. Later it was found that the loaded crystals were able to increase in height only when there were no unloaded crystals present in the same crystallizing dish. If unloaded crystals were placed in the crystallizing dish with a loaded crystal, or if volunteer crystals began to form soon after the experiment was started, then the loaded crystal did not show any increase in height, and in many cases there was an actual decrease in height.

Confirmatory experiments were made using other salts, such as copper sulphate and potassium sulphate, instead of alum.

In one of these experiments a crystal of potassium sulphate, 3.07 millimeters in thickness, was placed between two glass plates, held tightly together by rubber bands. The crystal and plates were then covered by a saturated solution of potassium sulphate and placed in a desiccator. Within a few days volunteer crystals began to form around the sides of the dish just above the surface of the solution, and a little later crystals appeared on the bottom of the dish. After several weeks the crystal pressed between the glass plates had gone completely into solution, while in the meantime the volunteer crystals had continuously grown in size.

From these experiments it would appear that when two crystals, similarly placed in a saturated solution, are subjected to unequal pressures the system is in unstable equilibrium. In other words a solution may become supersaturated with respect to a crystal placed under a relatively small pressure, while at the same time it tends to dissolve a crystal that is under a greater pressure. This probably explains why Bruhns and Mecklenburg failed to get the results that were obtained by Becker and Day.*

Experiments with results similar to those described above were performed by placing crystals in warm saturated solutions and allowing the solutions to cool down over night. In these tests supersaturation was induced by cooling, instead of by evaporation.

In another experiment a saturated solution of copper sulphate at room temperature (about 20° C.) was caused to flow slowly through a siphon to the bottom of a crystallizing dish, which was kept at a temperature of about 12° C. by surrounding it with running tap water. Another siphon with upturned ends kept the solution in the crystallizing dish at constant elevation. The arrangement of the apparatus is shown in fig. 1.

Before starting the flow of the solution through the apparatus, a crystal of copper sulphate, held tightly between glass plates surrounded by rubber bands, was placed in the crystallizing dish. The flow of solution was regulated by means of a pinch-cock so that about one liter passed through in twelve hours. At the end of twenty-four hours the growing crystal had pushed the plates apart, overcoming the resistance of the elastic bands, and had increased the distance between the plates from 1.21 to 2.63 millimeters. The experiment was discontinued

* On Dec. 29, 1915, several months after the completion of this work, the writer learned from Dr. J. C. Hostetter that, under the direction of Dr. A. L. Day, he had made experiments similar to those described above and reached the same conclusion. As the publication of Dr. Day's reply to Bruhns and Mecklenburg has been delayed, permission was courteously given to the writer to publish this paper without waiting for the appearance of that reply.

after a number of volunteer crystals had begun to develop in the crystallizing dish.

The foregoing experiments prove that under certain conditions the growth of crystals may be accompanied by the development of a linear force, and that the failure of some investigators to find evidence of this force is due to the conditions under which their experiments were conducted. The writer has formulated an hypothesis to explain the growth of crystals in directions in which mechanical hindrances oppose

FIG. 1.

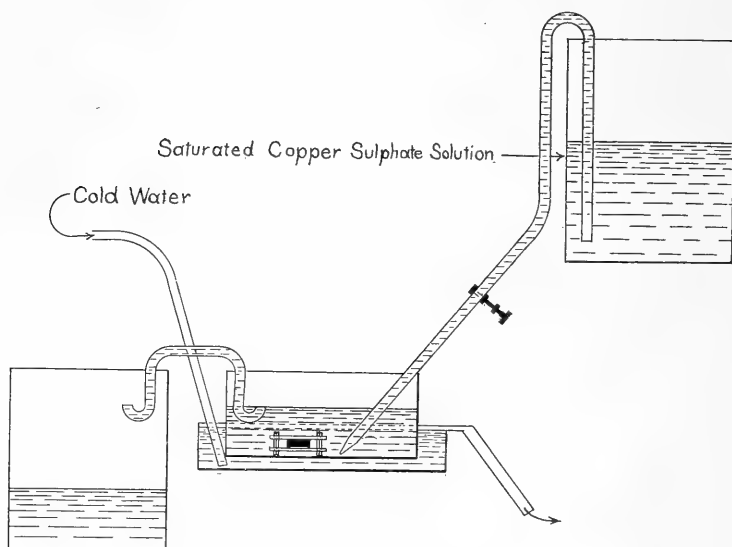


FIG. 1. Apparatus for growing crystals under pressure in a solution of approximately constant temperature.

growth, but since this problem is intimately related to the origin of the terraced cavities, it is necessary to consider both problems at the same time.

In all of the experiments described above, whenever a measurable lifting of a weight by a growing crystal took place, the crystal at the close of the experiment had a terraced cavity or hollow on its under side, and this was the case even when a crystal was used that had only plane faces in the beginning. In a very few instances indistinct shallow hollows seemed to be present also on the upper surface of covered crystals, but none had a depth of so much as 0.1 millimeter. Moreover, careful measurements show that the distances through which weights

are lifted by growing crystals are always the same as the amount by which their hollows are deepened. The results obtained in the experiment described below may be taken as typical.

A crystal of alun having a thickness of 2.18 millimeters was placed in a warm saturated solution and covered with a small glass plate. The solution was allowed to cool slowly in the crystallizing dish, which was left over night on a table in the laboratory. After about fifteen hours the crystal was taken from the solution, dried and remeasured. It was found to have increased 0.62 millimeter in total thickness, raising the glass plate through that distance, the cavity on the under side was deepened by 0.54 millimeter, and a shallow hollow, having a depth of 0.06 millimeter, was formed on the upper surface of the crystal. The increase in the depth of the cavities and the increase in the height of the crystal, therefore, differ by only 0.02 millimeter, which is well within the limits of error in making the measurements. All measurements were made with a screw micrometer graduated to 0.01 millimeter or with a spherometer similarly graduated, and the figures given above are the average of several independent determinations.

The hollows found on the under side of crystals are familiar to all who have grown them in glass vessels, for they are commonly formed on uncovered as well as covered and weighted crystals. Bruhns and Mecklenburg argue that the presence of these cavities does not indicate a lifting of the crystal by growth from below, and in support of this conclusion cite the experiment performed by Kopp in 1855, which they repeated with similar results.* They advanced the hypothesis that the formation of the narrow rim which surrounds the cavity and on which the crystal rests is due to adsorption, stating that the height of this rim does not increase with the growth of the crystal, and that it moves outward because of solution on the inner side, while it is continuously being built up anew on the outer edge. They further state that the height of the rim "about 0.12 millimeter" remains approximately constant during its outward growth, and that this is possibly connected with the thickness of the layer of solution between the crystal and its support.† It is clear that these statements do not agree with the results obtained in the experiments that the writer made with weighted crystals, but in order that there might be no uncertainty in this matter the following tests were conducted with crystals in free contact with the solution except, of course, on their under side, where they rested on the bottom of the crystallizing dish.

* Loc. cit., p. 101 and footnote 15, p. 113.

† Ibid., pp. 101-105.

Small crystals of alum colored with chrome alum (not more than 0.25 millimeter in diameter) were dropped into a warm saturated solution of plain alum, which was then allowed to cool down over night in the laboratory. Next morning, when the crystals were removed from the solution and measured they had an average diameter of 3 centimeters and height of 1.5 centimeters. The terraced hollows on the under side ranged from 2.38 to 3.21 millimeters in depth, and, at the top of each of these cavities, the small nucleal crystal, colored with chrome alum, could readily be distinguished; for it had not dissolved and no white alum had been deposited on its under surface. This means that these small nucleal crystals were elevated through a distance equal to about twelve times their original diameter.

In another test a small crystal of alum colored with chrome alum was placed in the solution of plain alum and allowed to grow until it had a diameter of 3 millimeters. It was then removed from the solution, dried, and the under surface given a thin coating of shellac. After the shellac had hardened, the crystal was replaced in a warm saturated solution, and allowed to grow over night as in the previous experiment. At the close of the test it was found that the impervious coating in no way had interfered with the deepening of the hollow, which was similar in every respect to the hollows formed in the crystals that had not been treated in this way.

Another crystal, with nucleus of chrome alum, was coated with shellac on all faces except the lower face, and then placed in a warm saturated solution as before. Deposition of new material took place first at the base and then gradually it covered all of the shellacked faces. The new faces were parallel to the old, but the new growth was easily broken from the original crystal along the shellacked surfaces, being firmly attached only at the base. The original crystal was elevated through a distance of 0.52 millimeter. A crystal, with all of its faces shellacked, did not grow in any direction when replaced in a saturated solution.

Most of the experiments outlined above were made with the alum crystals resting on an octahedral face, because flattened octahedrons are the commonest forms, and are also the easiest with which to work. When small (not more than 1 to 1.5 millimeters in height) these crystals frequently show only octahedral faces, but, as they grow more rapidly near the bottom than higher up, the larger crystals assume a terraced and roughly pyramidal form due to the alternation of octahedral faces and of octahedral and cube faces as shown in the cross-section, figure 2. In the several experiments made with crystals resting on cube faces, there seemed to be little if any

difference in their tendency to form cavities and raise the growing crystal.

One of the deepest hollows (2.93 millimeters) obtained by growing a crystal of alum in a solution that was allowed to cool down over night, was formed around an artificial plain surface which had been previously ground on the crystal in a direction not parallel to any of the natural faces. During the

FIG. 2.

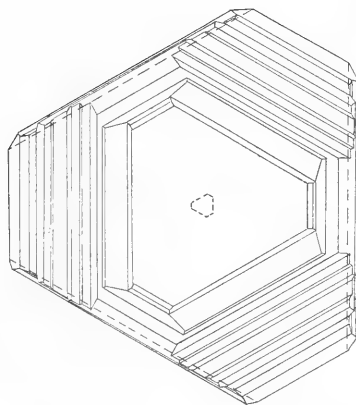
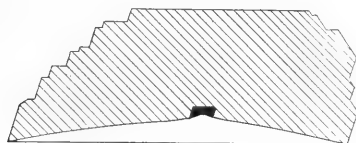


FIG. 2. Plan and cross-section of a large alum crystal with nucleal crystal colored with chrome alum. Crystal shows terraced pyramidal form and well-developed hollow on under surface.

growth of the crystal no appreciable change in the slope of the upper surface, which was a natural crystal face, could be observed.

When a crystal about 2 centimeters in diameter was placed upside down (i.e. with the hollow up) in a warm saturated solution, it grew a smooth surface on top similar in every way to the crystal that had not been reversed. Underneath the crystal a hollow, 0.6 millimeter in depth, was formed by the

downward extension of the new growth, the smooth flat face of the original crystal in the center of the hollow remaining unchanged. By coloring the original crystal with chrome alum the new growth could easily be distinguished from the old when the crystal was sectioned for examination.

The terraces on the under side of crystals are probably formed by the repetition of crystal faces, frequently they appear as minute striations parallel to the edges of the base, and sometimes they are unrecognizable, giving place to almost smooth sloping surfaces.

The experiments with weighted and unweighted crystals prove: (1) that a growing crystal resting on a smooth surface can raise itself and even a considerable additional load by building downward the advancing outward edge of the crystal; (2) that no material is deposited on the under side of the crystal except along the advancing outer edge; and (3) that the cavities are not formed by solution, but are due to the downward growth of the outer edge, while at the same time no material is being deposited on the under surface within this outer edge.

While it is true that there may be slow diffusion of molecules through solids and even through crystals, there is no ground for the belief that a crystal like an organism can grow from within. All of the experiments conducted by the writer support the theory that a crystal grows only through the addition of layers of material from without. If this is true, it follows that a crystal can grow only where it is in contact with a solution which furnishes it with the material necessary for growth. When crystals grow in contact with glass surfaces, as in the experiments described above, there is always a thin layer or film of solution between the crystal and the glass. The presence of this thin layer of solution is due to capillary attraction and adsorption. When the surrounding solution is more concentrated than the layer between the crystal and glass, diffusion is set up, tending to equalize the concentration, and, if the solution is supersaturated with respect to the base of the crystal, the crystal molecules present in excess of saturation are oriented and attached to the crystal as soon as they come within range of the molecular forces controlling crystal growth—a circumstance that must occur in such limited space not far from the outer edge of the crystal.

The area of contact between a crystal and the supporting surface is under greater pressure than the rest of the crystal, since it must bear the weight of the crystal as well as any added load. The solubility of most substances in aqueous solutions increases with the pressure, and therefore the supporting surface of a crystal of such a substance has a greater

solubility than the other parts of the crystal. Since a crystal is enlarged by deposition only at those points where it is in contact with a supersaturated solution, the degree of concentration necessary for crystal growth is greater at the base of the crystal than elsewhere. This means that a crystal is able to raise itself by downward growth, as in the experiments outlined above, only when its base is in contact with a solution supersaturated with respect to it, and that the degree of concentration necessary for growth increases with any increase in the weight supported per unit area of the supporting surface.

When supersaturation is brought about either by evaporation or by cooling, the denser and therefore more concentrated portions of the solution tend to settle to the bottom, and in the latter case the bottom of the crystallizing dish is itself a cooling surface. It is possible that adsorption in some slight degree helps to increase the concentration of the layer of solution in contact with the bottom of the dish, but adsorption can not be the direct cause of the upward pressure developed by crystals in the foregoing experiments, for otherwise the presence of unweighted crystals in the same dish with weighted crystals would not prevent the upward growth of the latter. The weighted crystals fail to grow in height because the unweighted crystals, with their lesser solubility, prevent the necessary degree of supersaturation in the layer of solution resting on the bottom of the dish. Another reason for believing that adsorption is of no importance in the formation of cavities and upward growth of crystals is the absence of appreciable hollows on the upper surface of crystals grown under heavy weights or even under glass plates weighing only 0.17 gram. There are no grounds for assuming that adsorption is any more efficacious in producing hollows on the under than on the upper surface of a crystal when both surfaces are in contact with similar material. In the few cases where insignificant shallow hollows were observed on the upper surface of crystals they were probably due to the cover plate acting as a cooling surface.

The objections raised against the adsorption hypothesis apply with equal force to the theory that the pressure accompanying crystal growth, in the experiments described above, is in any considerable degree due to those forces which are peculiar to the growth of crystals and which determine the development of crystal faces. The thin layer of solution due to capillarity and adsorption is always found between the upper surface of a crystal and the cover glass, as well as between the lower surface and its support; and the concentration of the solution in contact with the upper surface can be increased by diffusion from a surrounding solution of higher concentration just as easily as the solution under the base of the crystal. The upper

and lower surfaces of the crystals used are crystallographically the same, and therefore the forces controlling the development of crystal faces must be the same at the top as at the bottom. The pressure on the upper surface of a crystal is always less than that applied to the base, for the latter must also support the weight of the crystal, and therefore, all other things being equal, a crystal should grow through additions at the top rather than at the bottom. That this did not take place in the foregoing experiments leads inevitably to the conclusion that the upward pressure developed by the growing crystal must be explained by the presence of a solution, in contact with the base, having a greater degree of concentration than the solution in contact with the other surfaces of the crystal.

It is a well-known fact that when solutions of a salt, such as alum, are subjected to concentration, the denser and therefore more concentrated portions of the solution tend to settle to the bottom of the container. The roughly pyramidal form of the larger alum crystals has already been commented on, and this shape is unquestionably due to the more rapid growth of the lower parts of the crystal where they are in contact with the more concentrated layers of the solution.

If a crystal of alum is suspended just below the surface of a saturated solution in a large beaker and another crystal is placed on the bottom of the beaker, the latter crystal will grow in size at the expense of the former, which will go slowly into solution.

A crystal of alum 3 milligrams in weight was placed on a small glass plate suspended 2 centimeters above the bottom of the crystallizing dish containing a warm concentrated solution, while a similar crystal was placed on the bottom of another dish containing a solution of the same concentration and temperature. Both were allowed to cool down over night under exactly the same conditions. When the crystals were examined the next morning it was found that the crystal resting on the suspended glass plate had been raised through a distance of only 1.1 millimeters, while the crystal that had grown at the bottom of the crystallizing dish had been raised 2.4 millimeters.

The experiment described below illustrates nicely the difference in the growth of a crystal on its upper and lower surfaces because of the greater concentration in the lower layers of the solution. A perforated metal screen covered with a piece of filter paper was supported on glass rods so that it rested 3 millimeters above the bottom of a crystallizing dish containing a warm concentrated solution of alum. A crystal of alum colored with chrome alum was placed on top of the filter paper and covered first with a small piece of filter

paper and then with a piece of the metal screen. The holes in the screen were 1·5 millimeters in diameter and were spaced 0·75 millimeter apart. The solution was allowed to cool down over night and the following morning the crystal was removed, sectioned vertically and carefully examined. It increased in height from 4·69 to 5·15 millimeters through the addition of material to the lower surface, and the hollow in the original crystal was almost entirely filled. Moreover, the crystal had grown downward in places through the pores of the filter paper, as there were several crystals, oriented parallel to the original crystal, attached to the under side of the lower metal screen. There was no deposition of new material on the upper face of the crystal and no growth through the paper such as was observed underneath, although the crystal grew outward until beyond the limits of the overlying filter paper and screen, and then upward and also inward until the new growth overlapped the screen on top. The pressure of the filter paper and screen, weighing less than 0·5 gram, was sufficient to prevent any growth on the upper surface of the crystal or in the pores of the filter paper. Growth continued downward through the pores of the lower filter paper because the concentration of the solution increased in that direction.

In another set of experiments, growing crystals of alum, copper sulphate and potassium sulphate were subjected to lateral pressure between pairs of vertical glass plates while in all other directions they were in free contact with supersaturated solutions. These crystals grew in every direction, except that in which the pressure was applied, forming flat tabular crystals. They could not overcome the external pressure resisting growth, because there was no provision for supersaturating the solution with respect to the faces that were under pressure and that were thereby rendered more soluble.

A consideration of the results obtained in the foregoing experiments leads to the following conclusions:

(1) A crystal will grow in a direction in which external forces oppose growth, if the surface on which the forces are acting is in contact with a solution that is supersaturated with respect to it; and, if the growing crystal is composed of a substance the solubility of which increases with pressure, then for any increase in the forces opposing growth a corresponding increase in the concentration of the solution is necessary.

(2) If a crystal of such a substance is subjected to a greater pressure in one direction than in others (as for example when a weight is placed on a crystal), the surfaces that are under the lesser pressure will tend to limit the concentration of the solution and prevent it from becoming supersaturated with

respect to the surfaces that are rendered more soluble because of greater pressure. In order that growth may also take place on the surfaces subjected to the greater pressure, some means must be provided for maintaining the supersaturation of the solution in contact with them.

In their conclusions concerning the area of contact between a growing crystal and the supporting surface, Becker and Day state that "there is reason to believe that this area changes constantly as the crystals grow, and is less for a smaller load than for a larger one."* When a supersaturated solution is diffusing under the edge of a growing crystal, growth is most rapid on the outermost edge, and the concentration of the solution decreases rapidly with the distance that it has to diffuse under the crystal. As growth takes place and the crystal is raised this tends to keep the outer edge, supporting the weight of the crystal, as narrow as possible, but the area of the edge must always be large enough to keep the pressure per unit area less than the crushing strength. Moreover since the solubility increases with the pressure the area of the supporting surface must always be sufficient to maintain the relative supersaturation of the solution with respect to it and prevent re-solution. This argument leads to the conclusion that the area of support may also be dependent on the relative concentration of the solution with which it is in contact. It is difficult to obtain the quantitative data that would confirm this conclusion, but observation seems to support the view that the area is smaller when in contact with a highly supersaturated solution than when the solution is almost at the saturation point.

The molecular forces enabling crystals to grow in directions in which they must overcome external pressure, furnish the most plausible explanation of certain geologic phenomena; but hollow faces such as those obtained in the foregoing experiments are not common in minerals, and their absence has been used as an argument against this hypothesis. In nature, however, crystal growth usually takes place at a much slower rate than is feasible in laboratory experiments, and the rock masses in contact with a growing crystal are more or less permeable to solutions. That solutions are active agents even in relatively impervious rocks, like granite, is indicated by the reactions that take place not only in fractures but also along the contact between different minerals and even along the cleavage planes of the minerals themselves.

In attempting to reproduce under laboratory control the needle-like ice columns that are commonly found on bare clayey soils after a cool night, the writer observed that water

* Loc. cit., p. 287.

in fine capillary tubes remained in a liquid state at very low temperatures.* This suggested the following experiment: A half-inch glass tube and a fine capillary tube were filled with a concentrated solution of copper sulphate and sealed. The

FIG. 3.

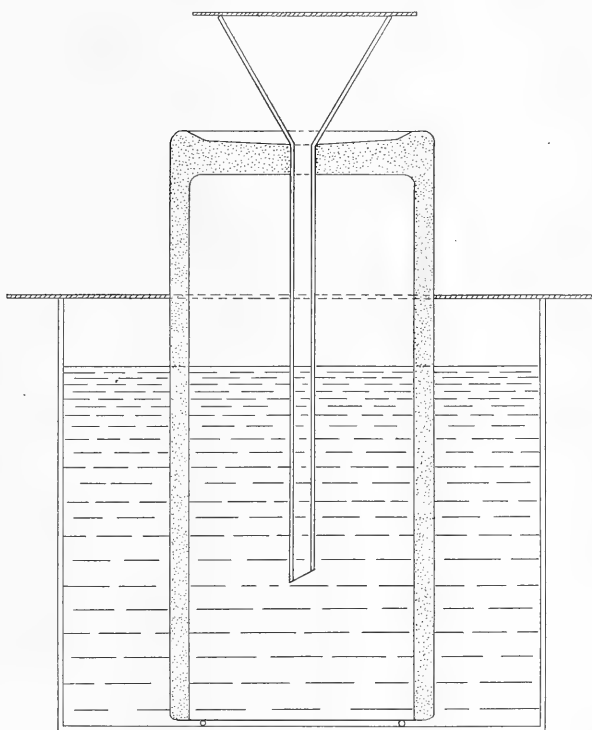


FIG. 3. Porous battery cell in a saturated solution of copper sulphate. The solution is drawn up through the capillary pores and on evaporating from the upper surfaces deposits crystals which rupture the cell and gradually form veinlets.

temperature was then lowered until crystals began to separate out in the large tube, but crystallization did not take place in the capillary tube even when it was kept at a much lower temperature for several days. The discovery of this fact led to a series of experiments with porous materials, two of which are described below.

*This fact seems first to have been observed and recorded by Sorby, *Phil. Mag.* (4), vol. xviii, p. 105, 1859.

A porous battery cell was placed bottom up in a glass jar, about three-fourths full of a saturated solution of copper sulphate, and a piece of paraffine-coated cardboard was cut to fit snugly around the cell and rest on top of the jar, as shown in figure 3. The purpose of the cardboard was merely to prevent evaporation from the surface of the solution in the jar. The battery cell was 18 centimeters high and 8 centimeters in diameter while its walls averaged 6 millimeters in thickness. The stem of a glass funnel was inserted through a small hole drilled in the bottom of the cell so that the solution could be replenished and kept at the same elevation. The solution was slowly drawn up through the capillary pores of the cell allowing evaporation to take place from the exposed surface. After a couple of days a coating of copper sulphate began to form here and there in irregular spots. These spots gradually increased in size and thickness to form thin crusts, and, later, groups of short needle-like columns of copper sulphate normal to the surface of the cell, could be observed gradually pushing the crusts outward. The columnar crystals also appeared in large and small groups elsewhere on the surface of the cell, and on the outer ends of some of these, small fragments of the cell could be distinguished. After about ten days narrow cracks were seen forming in the walls of the cell. At first they seemed, for the most part at least, to be open fissures, but the openings were gradually filled with copper sulphate so as to form veinlets, and, as the veinlets became larger, it could be seen that the copper sulphate crystals were in the form of needle-like columns or fibers with their axes normal to the walls of the fracture. The veins were usually enlarged by growth from both sides, as was shown by the presence of an irregular parting near the center marked by a line of small cell fragments. Occasionally where one side was cut off from additional supplies of solution the crystals would grow without break across the entire vein. In structure and appearance these veins closely resemble the asbestos veins in serpentine, and this suggests that the latter have possibly grown out from the walls in a somewhat similar manner. In places the veins give way to a brecciated zone in which the individual fragments are separated from one another and held in place by the copper sulphate. When the experiment was discontinued some of the veins had a width of over 3 millimeters, and the columnar crystals growing normal to the surface of the cell had a length of about 1 centimeter.

After several attempts to break glass receptacles with growing crystals a method was devised that proved successful. In this experiment crystals of copper sulphate were grown in a bulb-shaped chamber 4.5 centimeters in diameter, blown in a

glass tube having an interior diameter of 7 millimeters. The walls of the chamber were about 0.3 millimeter thick. The apparatus was set up as shown in figure 4. A saturated solution of copper sulphate at room temperature (about $20^{\circ}\text{C}.$)

FIG. 4.

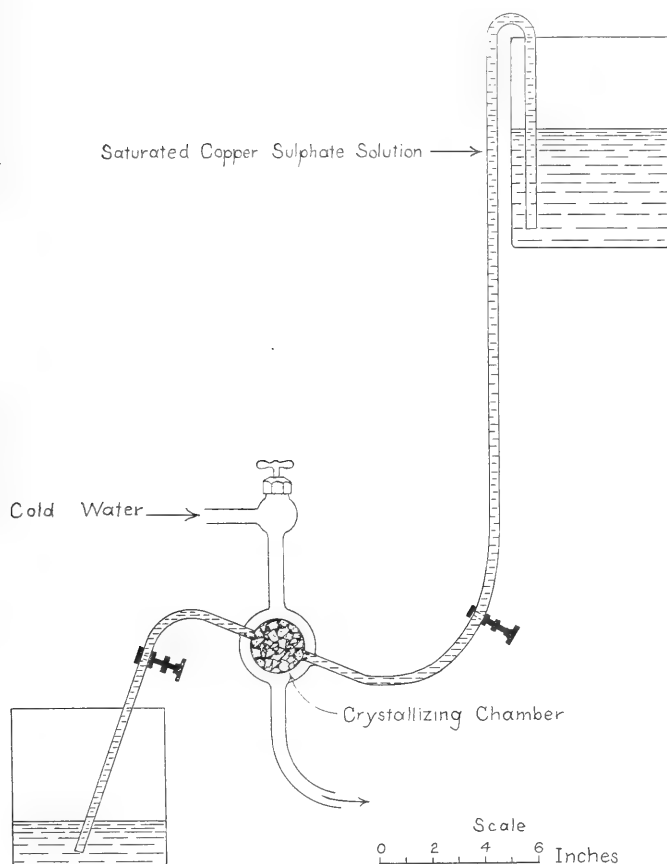


FIG. 4. Apparatus for growing crystals under pressure, with glass crystallizing chamber ready to be ruptured by growing crystals.

was drawn from a large reservoir by means of a glass siphon and passed through the crystallizing chamber, the rate of flow being controlled by a pinchcock placed near the end of the outflow tube. The surface of the solution in the reservoir stood at an average elevation of about 50 centimeters above the crystallizing chamber. The latter was kept at a

lower temperature than the reservoir by surrounding it with running tap water having an average temperature of about 12° C. The chamber was first filled with fragments of a broken battery cell together with a few small crystals of copper sulphate to induce crystallization, and then the interstices were filled up with clean, fine quartz sand. Upon admitting the solution, care was taken to remove, as far as possible, all air bubbles from the apparatus. In the beginning the flow of the solution was regulated so that about two liters passed through in twenty-four hours, but toward the close of the experiment, as the passageways became choked with crystals, the flow became slower and slower. After starting the experiment, it was kept in continuous operation until the chamber was ruptured, which occurred at the end of 9 days in one test and 7 days in another.

After one of these tests, the mass filling the ruptured chamber was immediately broken to pieces and carefully examined. The outer portion of the mass was thoroughly cemented together so that the surface in contact with the glass was almost smooth, but near the center some of the spaces were only partly filled by deposition. The crystals of copper sulphate had sharp boundaries along their contact with the quartz grains and cell fragments. No fibrous or columnar crystals could be found, and, when freshly broken pieces were examined under a bifocal microscope, magnifying to 78 diameters, no copper sulphate crystals were observed in the pores of the cell fragments except occasionally where there were unusually large openings.

After completing the other test, the ruptured glass chamber, with its contents, was set aside and allowed to stand undisturbed for several weeks. The solution remaining in the chamber at the close of the experiment gradually reached the surface by capillary attraction, and evaporated where exposed to the air along the fractures in the glass. The evaporating solutions built up crystals in the fractures, and the glass fragments were pushed farther apart, but none of these crystals showed a columnar or fibrous structure.

During these investigations another observation was made that throws some additional light on the manner of crystal growth under varying conditions. After a test in which the flow of solution through the glass crystallizing chamber had been nearly stopped by crystal growth, the apparatus was disconnected without rupture having occurred, and, with the tubing still full of solution, was placed in a beaker, as shown in fig. 5, where it was allowed to stand undisturbed for three months during the summer. The pressure of the solution standing in the longer tube caused the solution to flow very

slowly from the open end of the shorter tube, where it evaporated. At first the solution ran down between the tube and the beaker for a distance of 8 centimeters, forming on evaporation a crust that in places attached the tube to the beaker. Later, the flow became adjusted to the evaporation in such a

FIG. 5.

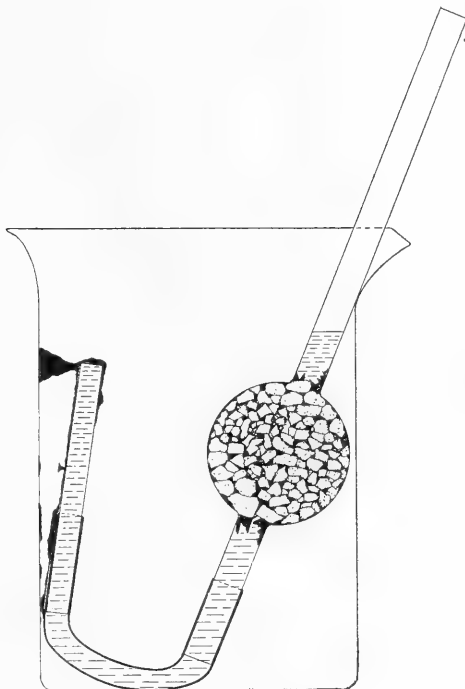


FIG. 5. Diagram showing glass tube gradually being pushed back from the side of the beaker by a growing mass of copper sulphate crystals.

way that crystal growth continued only where the crust of copper sulphate was in contact with the beaker near the top of the tube. Gradually a hollow growth, shaped somewhat like a stalactite, was formed between the end of the tube and the beaker. As it increased in size the tube was pushed back 1.3 centimeters against the elastic resistance of the rubber tube connecting the two glass tubes, and the mass that had formed lower down between the tube and beaker was pulled apart, leaving fragments adhering to both. Additions of material seemed to take place only where the formation was in contact

with the side of the beaker, and the rate of growth was probably not uniform, as rings of growth varying in thickness and also in fineness of crystallization could be distinguished. The successive rings gradually increased in diameter so that the formation was largest at the end in contact with the beaker. The rings are probably due to variations in the rate of growth resulting from changes in temperature and humidity. In this case the material for growth diffused under the growing mass from within instead of from without.

The shape of a crystal is the resultant of several different factors, and under varying conditions these factors vary greatly in their relative importance. In the ideal case of a growing crystal, everywhere in contact with a solution of uniform saturation, it is probable, as suggested by Lehmann, that the form assumed is the resultant of the forces of surface tension and molecular orientation.* The tendency is always to build that form for which the total surface energy is a minimum, and in crystals the surface tension is not the same in different directions. Otherwise the stable form would be a sphere.

In nature this ideal condition can seldom be attained, and in most cases the form of a growing crystal is determined by the external forces resisting growth and the accessibility of the material from which the crystal is built rather than the tendency to form crystal faces. The tendency to form crystal faces is much stronger in some substances than in others, but it is never so strong as to cause growth on a face which is not in contact with a supersaturated solution, and, even if a growing surface is in contact with a supersaturated solution, the relative rate of growth is chiefly controlled by the rapidity with which the material for growth is made available.

If a solution remains in contact with two substances, A and B, it will in time become saturated with respect to both, and should the conditions change so that the solution is supersaturated with respect to A, then the crystals of A will begin to grow. With increase in size a crystal of A will finally approach so close to a crystal of B that the latter will offer resistance to further growth in that direction. If, under existing conditions, A has a relatively weak tendency to form crystal faces and a relatively rapid rate of growth, the crystal of A will grow around the crystal of B, which will then become an inclusion; but on the other hand, if A has a relatively strong tendency to form crystal faces and a relatively slow rate of growth, so that there will be sufficient time for diffusion to supply new material to the surface of A along its contact with the crystal of B, then B must make room for the crystal of A.

* Quoted in J. V. Elsden's "Principles of Chemical Geology," p. 60. London, 1910.

It may do this in two ways: if the pressure exerted by the crystal of A on B renders the latter more soluble, and sufficient time is allowed, B will go into solution where the pressure is greatest, and crystallize out again where the pressure is least; but should conditions be otherwise, B must be pushed out of the way by the growing crystal of A.

Water is universally present in rocks, though often in very small quantities, and the recrystallization of minerals is largely brought about through the agency of aqueous solutions. The growth of garnet crystals in certain quartz-mica schists studied by the writer furnishes a good illustration of the processes described above. The garnets referred to are of later origin than the schistosity of the rock, which, under the microscope, is seen to consist essentially of elongated quartz grains and small flakes of mica, the two minerals being interleaved to form thin layers or imperfect alternating bands. The garnets in their growth have pushed aside the relatively insoluble plates of mica so that opposite the garnets the mica layers run closer together, while the more soluble quartz has been removed from these points of greatest pressure, and redeposited between the folia, where the supporting effect of the garnets resulted in a reduction of pressure. The recrystallized quartz grains are roughly elongated and oriented, so that their longer dimensional axes radiate outward from the garnets.*

So far in this discussion only the growth of individual crystals has been considered. In the growth of crystalline aggregates the molecular forces controlling the formation of crystal faces can have little to do with the shaping of the mass as a whole, which is, therefore, determined by the external forces resisting growth and the accessibility of the material from which the growing mass is composed. During the growth of such a mass, the tendency is to produce that form which requires the least expenditure of energy, and if the resistance to growth were equal in all directions, the growing body would tend to become spherical; but usually the accessibility of material is an influential, if not the controlling, factor. The shape of calcareous concretions formed in shales furnishes an illustration of the growth of crystalline masses where growth is opposed by the resistance of external forces.

The hollow faces and also the needle-like columnar crystals, obtained in the experiments described in this paper, are to be attributed to the limited accessibility of the materials necessary for growth. The formation of the hollow faces, as already explained, is due to the rapid growth of the outer edge of a crystal face in contact with a smooth supporting surface, and

* Taber, S., *Geology of the Gold Belt in the James River Basin, Virginia*, Va. Geol. Surv., Bull. No. VII, pp. 29-30 and 228-229, 1913.

the consequent reduction in the concentration of the solution tending to diffuse in under the crystal. A concave surface is less soluble than a plane surface, and, therefore, hollow faces are soon filled up except in those cases where crystal growth is so rapid as to reduce the concentration of the solution faster than diffusion can supply material to the less exposed surfaces.

The form of the needle-like columnar crystals of copper sulphate obtained by the writer is determined by the fact that each crystal is in contact with the solution furnishing the material for its growth only at its base. The material for growth is supplied through capillary openings so small that their surface tension is sufficient to prevent the solution from creeping up the crystals. The enlargement of these columnar crystals takes place only in the direction of greatest pressure, but this phenomenon is due merely to the circumstance that in other directions the crystals are not in contact with the solution. The long slender columnar form is never found in crystals of copper sulphate that have grown normally with the solution in contact with several surfaces, because this form is not the most stable. The total surface energy of one of the columnar crystals is great as compared with the mass, and, therefore, they are dissolved by solutions that are supersaturated with respect to more stable crystal forms. If the columnar crystals are placed in saturated solutions with normal crystal forms, the latter tend to grow at the expense of the former in the same way that large crystals replace smaller ones.

The same argument applies to the formation of ice columns. The ice columns are usually capped by sand grains, small pebbles, etc., which, as pointed out by Prof. Abbe,* have probably acted as refrigerating surfaces and served as nuclei for the crystallization of the ice. These nuclei are not essential, however, and are sometimes absent even in nature. Numerous experiments carried on by the writer with different kinds of material, varying quantities of water, and different methods of insulation and refrigeration all lead to the same conclusion: The essential condition for the formation of ice columns is that the water for the growth of the ice column must be delivered through a small capillary opening to the base of the growing crystal which must not elsewhere come in contact with water.

There are of course other ways in which elongated, columnar and even fibrous crystals may be formed. In some crystals, such as rutile needles, the form is probably due solely to the molecular forces controlling the formation of crystal faces; while in other cases external forces have been the controlling

*Abbe, Cleveland, *Ice Columns in Gravelly Soil*, *Monthly Weather Review*, vol. xxxiii, pp. 157-158, 1905.

factor. Where the elongated form develops chiefly as a result of external pressure, the longer dimensional axes are normal to the direction of greatest pressure and parallel to the least pressure. Van Hise and others have explained the development of elongated crystals during the recrystallization of rocks on the theory that solution takes place along the line of greatest strain and deposition along the line of least resistance and normal to the maximum stress. This theory is confirmed by the experiments of F. E. Wright in the formation of crystals of wollastonite, diopside and anorthite under vertical pressure.* If the normal habit of a mineral is columnar, then those crystals that are oriented with their longer axes parallel to the least pressure will tend to grow at the expense of those that are not so favorably oriented. When columnar crystals develop parallel to the direction of the greatest pressure, as in the experiments with copper sulphate and ice described in this paper, the orientation is in spite of the pressure and not because of it.

Attention has been called to the fact that crystallization does not take place so readily in very small capillary spaces. It is possible that the high surface tension and extremely small volume of the solution may tend to prevent the development of centers of crystallization.

The solution, furnishing the material necessary for growth to a crystal surface that is under pressure, may consist of a layer so thin that the space occupied must be classed as subcapillary rather than capillary in size. A subcapillary opening, as defined by Van Hise, is one in which the attraction of the solid molecules extends from wall to wall.† The flow of solutions through such extremely minute openings must be exceedingly slow, and therefore it is probable that the material for growth reaches the growing surface largely as a result of diffusion even in the case of natural crystals which have grown gradually through a long period of time. It would be very difficult, if not impossible, to expel solutions from subcapillary openings solely through the application of pressure, and therefore, under favorable conditions, the material for growth may be able to reach a crystal that is under very great pressure—a pressure that is perhaps several times the crushing strength of the crystal.

The pressure that may sometimes be observed during the growth of a crystal is probably due to the molecular forces associated with the separation of solids from solution and the

* Wright, F. E., *Schistosity by Crystallization*, A Quantitative Proof: this Journal, vol. xxii. pp. 224-230, 1906.

† Van Hise, C. R., *Treatise on Metamorphism*, U. S. Geol. Surv., Monograph 47, p. 135, 1904.

attraction and orientation of the physical molecules as they are brought into position on the surface of a growing crystal, but the exact mechanical process (or processes) is uncertain. It seems probable that several closely related processes are involved. While the forces that control the development of crystal faces may enable a growing crystal to exert a linear force that is greater in some directions than in others, "this crystallizing force" is probably small. This force was not quantitatively determined in the experiment by Becker and Day, and it is doubtful if it can be directly determined.

A crystal surface will not grow under pressure and therefore will not do work in overcoming external forces resisting growth unless the surface is in contact with a supersaturated solution. From this it follows that any factor affecting the solubility of the surface will correspondingly affect the amount of work which may be done by a growing crystal in contact with a definite quantity of supersaturated solution. If a growing crystal is everywhere in contact with a solution of uniform concentration, then the pressure that may be developed in any given direction will depend upon the solubility of the crystal in that direction and the way in which the solubility varies under pressure. In crystals, the solubility is equal along all parallel directions, and, with certain exceptions, it is unequal along directions which are not parallel. The solubility of most substances increases with the pressure, and in crystals the rate of increase is probably the same only in parallel directions. A convex surface has a greater solubility and a concave surface a less solubility than a plane surface, and, therefore under uniform conditions, the tendency is always to form plane surfaces. The crystal faces that most commonly develop are normal to the directions of greatest solubility under the existing conditions, while the crystal edges and crystal angles develop in the directions of least solubility. The writer suggests that the intensity of the "crystallizing force" for a crystal of any substance under given conditions might be estimated after experimentally determining the relative solubilities under varying pressures in different directions.

It is possible that the pressure effects studied in this paper are not limited to crystals, for it is readily conceivable that the same forces of molecular cohesion, which enable any solid to resist external forces tending to cause rupture, could exert, during the enlargement of the mass, a pressure that would be of the same order of magnitude as the forces necessary to produce rupture. Moreover there is another factor involved that may be of prime importance. Most substances, so far as we know, dissolve in water with a net decrease in the volume of the system. In some cases the volume of the solution is even

less than the volume of the water alone.* All the salts used in the experiments described in this paper go into solution with contraction in volume. The writer has tried to obtain some evidence of pressure during the crystallization of ammonium chloride, one of the few salts that dissolve in water with an expansion in the volume of the solution, but so far has obtained only negative results. This question, however, is not regarded as settled, and the experiments are being continued.

Pressure tends to increase the solubility of a salt that goes into solution with a contraction in the total volume. The separation of such a salt from solution must be accompanied by a corresponding increase in volume, and if the separation takes place in a closed and limited space, the pressure developed may be enormous, probably many times the crushing strength of the substance.

If a crystal or crystalline mass should be so enclosed by other matter that the material for growth reached it only by diffusion through subcapillary openings, then the pressure developed during crystallization might be very largely due to the accompanying increase in volume. If this hypothesis proves to be true it may help to explain the variation in the character of the concretions found in rocks that differ in texture. Those concretions, that largely exclude the material composing the rock in which they grow and in so doing push apart the planes of lamination, seem to be limited chiefly, if not entirely, to the fine-grained rocks, such as shales and slates, in which the openings are for the most part subcapillary in size. On the other hand there are many concretions that are relatively impure, because they include much of the surrounding material, and these do not show any evidence of having exerted pressure on the inclosing rock, since the bedding planes of the latter may often be traced through the concretions without break in their continuity.

This class of concretions seems to be limited largely if not entirely to sandstones and other coarser-textured rocks in which the openings are for the most part capillary and supercapillary in size. In extreme cases the concentrated matter merely fills the interstices and cements loose-textured material together to form indistinct nodular masses.

Highly pure siliceous concretions and pyrite crystals may develop in limestones and similar calcareous rocks without disturbing the enclosing material, for such rocks are relatively

*Thomsen, *Therm. Untersuch.*, I, 45, 1882. MacGregor, *Trans. Roy. Soc. Can.* 1890, 19; 1891, 15. *Trans. Nova Scotia Inst. Sci.*, vii, 368, 1890. Traube, *Zs. anorg. Chem.*, iii, 1, 1892. These references cited in G. P. Baxter's "Changes in volume upon solution in water of the salts of the alkalis," *Jour. Am. Chem. Soc.*, vol. xxxiii, p. 922, 1911.

soluble, and go easily into solution where subjected to pressure by a growing body.

The writer believes that the forces developed during crystal growth have played an exceedingly important part in the formation of many veins. In an earlier publication some of these veins were described in detail and many of the facts supporting this hypothesis were given,* but additional evidence is now available. A paper is at present under preparation in which the experimental data so far established, together with such observational data as have been collected, will be used in attempting to explain various geologic phenomena, especially the formation of veins.

SCIENTIFIC INTELLIGENCE.

I. CHEMISTRY AND PHYSICS.

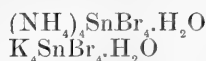
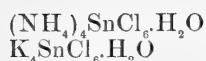
1. *Stannous and Lead Double Halogen Salts*.—E. RIMBACH and K. FLECK have prepared a number of these double chlorides and bromides. They are ammonium and potassium salts with the exception of one rubidium compound. The investigation appears to have been carried out systematically and skillfully, so that all the salts that could be crystallized from aqueous solution were generally obtained. The following salts with lower ratios of alkaline halide to bivalent halide were obtained :

1 : 2	2 : 1
RbPb ₂ Cl ₆	(NH ₄) ₂ SnCl ₄ .H ₂ O
	K ₂ SnCl ₄ .H ₂ O
1 : 1	K ₂ SnCl ₄ .2H ₂ O
NH ₄ SnCl ₃ .H ₂ O	(NH ₄) ₂ SnBr ₄ .H ₂ O
KSnCl ₃ .H ₂ O	K ₂ SnBr ₄ .H ₂ O
NH ₄ SnBr ₃ .H ₂ O	
KSnBr ₃ .H ₂ O	
KPbCl ₃	

All of the above salts were previously known, and all of the tin compounds had been described in 1892 by Richardson who worked at Johns Hopkins University under the direction of Professor Remsen. Richardson was unable to prepare any 4 : 1 salts corresponding to (NH₄)₄SnCl₆.3H₂O and K₄SnCl₆.3H₂O, which had been described by Poggiale in 1842, but in the investigation under consideration four of these tin salts were produced, as well as a corresponding lead salt:

* Taber, S., *Geology of the Gold Belt in the James River Basin, Virginia*, Va. Geol. Surv., Bull. No. VII, pp. 222-231, 1913.

4 : 1



These salts are of considerable interest, since they confirm the type made by Poggiale and since they correspond in type to the caesium salts Cs_4PbCl_6 and Cs_4PbBr_6 prepared by G. F. Campbell and by P. T. Walden, and described in this Journal, Feb. 1893. They are exceptions to a rule advanced by Professor Remsen requiring that the number of alkaline halide molecules in a double halide shall not exceed in number the halogen atoms of the more negative halide.—*Zeitschr. anorgan. Chem.*, civ, 139.

H. L. W.

2. *The Production of Liquid Hydrocarbons from Naphthaline.*—Naphthaline is one of the large products of the distillation of coal tar, its annual production in Germany being about 80,000 tons. Its chemical applications are limited, so that the greater part of it is used for fuel. FRANZ FISCHER has applied Friedel and Crafts' reaction to this material, using only about 5 per cent of aluminium chloride and heating under pressure with the result that a liquid product amounting to about one-third of the weight of the naphthaline was obtained. Upon refining this by distillation and other treatment, an oil distilling between 150° and 300° C., amounting to about 18 per cent of the original naphthaline, was obtained. It appeared to consist partly of dihydronaphthaline. It did not burn satisfactorily in an ordinary kerosene lamp as the flame was smoky. Possibly a modified lamp admitting a larger supply of air might use it.—*Berichte*, xlix, 252. H. L. W.

3. *The Application of Paper Pulp as a Filter in Quantitative Analysis.*—S. L. JODIDI and E. H. KELLOGG recommend the use of filter paper pulp in a Gooch crucible for filtering and weighing barium sulphate, silver chloride, potassium platonic chloride, and ammonium platonic chloride. They state that results obtained in this way are as accurate as those obtained with "standard filter paper," and that considerable time and labor are saved. Although this article has been published "By permission of the Secretary of Agriculture," the advice does not appear to be good. The use of paper pulp for filtration is already very well known, but probably it has seldom been used in place of asbestos for weighing precipitates in the Gooch crucible, because it is less satisfactory and much less convenient. The proposed method seems to be a backward step towards the former extensive use of "tared filters," which at present are avoided as far as possible. The proposed operation with barium sulphate, where the pulp is to be burnt by putting the Gooch crucible into a larger platinum crucible, is certainly cumbersome and unsatisfactory.—*Jour. Indust. and Eng. Chem.*, viii, 317. H. L. W.

4. *The Gases of the Atmosphere*; by SIR WILLIAM RAMSAY. Fourth Edition, 8vo, pp. 306. London, 1915 (Macmillan & Co.,

Limited).—The first edition of this very interesting book appeared in 1896, soon after the discovery, by Lord Rayleigh and the author, of argon in the atmosphere. It gives the history of the discovery of the better known constituents of the air in popular language and in a very entertaining way, and thus leads up to an excellent description of the work on argon. Full-page portraits are presented of the prominent early investigators of the atmosphere: Hales, Boyle, Mayow, Black, Rutherford, Priestly, Scheele, Lavoisier and Cavendish. The latter had collected argon from the atmosphere and had purified it perfectly more than 100 years before Rayleigh and Ramsay named it. Readers of the book will regret that it contains no portraits of the author, of Lord Rayleigh, of Travers, of Madame Curie, of the modern Rutherford, of Soddy, and of other recent discoverers in the domain of atmospheric gases. To the second edition of the book, in 1900, a chapter was added dealing with helium, neon, krypton and xenon. In 1905, the third edition gave an account of the radioactive gases, and this chapter has been extended in the present edition. There is probably no scientific achievement of more general interest than the explanation of our atmosphere, and the story is admirably told in this book. A considerable amount of instruction in elementary physical and chemical theory is presented for the sake of those who need it, while the historical matter, including the explanation of the curious phlogistic theory, is very suitable reading for students of chemistry and physics.

H. L. W.

5. *Metallurgists and Chemists' Handbook*. Compiled by DONALD M. LIDDELL. 12mo, pp. 603. New York, 1916 (McGraw-Hill Book Company, Inc. Price \$4).—This is a reference book of tables and data which is conveniently and attractively printed and bound with the use of thin paper, gilt edges, and a flexible leather cover. It is divided into sections dealing with mathematics; price and production statistics; physical constants; chemical data; sampling, assaying and analysis; ore dressing; cyanidation; fuels and refractories; mechanical engineering and construction; general metallurgy; and first aid. There is also a good index. The book contains a vast amount of useful information, and it will undoubtedly be of much value to metallurgists and metallurgical chemists as well as to students preparing for these professions.

H. L. W.

6. *Ampère Molecular Currents*.—The modern electronic form of Ampère's hypothesis that magnetic substances owe their magnetic properties to the circulation of electricity in natural circuits of molecular or atomic dimensions seems to involve certain difficulties, such as the decrease in the magnetic moment of a paramagnetic atom due to radiation, the existence of the so-called "absolute-zero energy," etc. Hence any experimental research on this subject which leads to definite results is of great interest and importance. A brief outline of an investigation of this sort, which has been recently carried out by A. EINSTEIN and W. J. DE HAAS, will now be given.

According to Ampère an electric current is associated with a magnetic field equivalent to that of a magnetic shell whose magnetic moment m is equal to the product of the current i and the area of the enclosed surface F . In the case of a charged particle moving around the circumference of a circle the current is equal to the product of the number n of revolutions per second by the charge e of the particle, that is, $m = iF = e n F$. Considered vectorially, the magnetic moment is perpendicular to the plane of the orbit and is related to the direction of circulation of the elementary charge according to the right (positive charge) or left (negative charge) hand screw law. Again, as may be readily shown, the angular momentum M of the charged particle of Newtonian mass μ is given by the equation $M = 2 \mu n F$, consequently $\mathbf{M} = \frac{2\mu}{e} \mathbf{m}$. This relation may be extended to all the

electrons and molecules in a body of ordinary size, and it then assumes the form $\mathbf{M} = -1.13 \times 10^{-7} \mathbf{J}$, where \mathbf{J} denotes the volume integral $\int \mathbf{m} d\tau$. Finally, we obtain $\mathbf{D} = 1.13 \times 10^{-7} \mathbf{v} \times \mathbf{J}$ in which \mathbf{D} and \mathbf{v} symbolize respectively the mechanical moment and the angular velocity of the extended magnetic body. This moment is analogous to that which governs the motion of precession in the theory of gyroscopes. The rest of the analysis consists in deriving equations for the motion of the fundamental parts of the apparatus employed.

The experimental investigation was divided as usual into two parts, (a) the qualitative verification of the phenomena predicted on the foregoing theory, and (b) a more exact quantitative test of the theoretical deductions. Although the first part of the work is very interesting and leaves no doubt concerning the validity of the theory, we shall turn our attention at once to the final experimental procedure.

The perfected apparatus consisted of two fundamental parts, namely, a hollow coil of insulated wire with its axis of figure vertical, and a slender rod of iron suspended coaxially in the coil by means of a fine glass fiber. In order to completely reverse the magnetization of the iron rod (as the theory presupposes) the dimensions of the apparatus had the following values. The coil was 62^{cms} long and had about 100 turns per cm. A current of 1.45 amperes produced fields of 260 and 130 gauss at the middle and ends of the coil, respectively. To minimize the demagnetizing effect of the poles the iron rod was made 16^{cms} long and 0.17^{cm} in diameter. A very thin glass tube, which was cemented to the lower end of the iron rod, projected below the coil and carried a tiny mirror which reflected the "light lever" and thus enabled the experimenter to observe the amplitudes of the rotations of the rod around its vertical axis. By varying the frequency of the alternating current in the coil and noting the corresponding angular elongations the data for a resonance curve were obtained. This curve has the general appearance of a slightly asymmetric "error curve" with such steep sides that the maximum can be

determined with ease and accuracy. The data also show that the assumption of a linear damping term in the equation of motion of the iron cylinder was fully justified. By substituting the experimental numbers in the working formula it was found that $\frac{2\mu}{e}$ had

the value -1.11×10^{-7} which is in excellent agreement with the accepted datum -1.13×10^{-7} . The problem has now been successfully attacked in converse ways: the above authors varied the magnetization and found the predicted mechanical rotation, while S. J. Barnett (*Science*, July and October, 1915) imparted a great angular acceleration to a specimen of iron and demonstrated the existence of a magnetomotive force.—*Verh. d. deutsch. physik. Gesell.*, No. 8, p. 152, and No. 22, p. 420, 1915. H. S. U.

7. *Refraction of X-Rays*.—On the simple theory of dispersion the formula for the square of the refractive index involves the sum of terms of the type $N e^2 \pi^{-1} m^{-1} (n_0^2 - n^2)^{-1}$, where n_0 and n denote respectively the frequency of vibration of the oscillators and of the incident radiation. As the frequency of the incident radiation increases from n , for visible light, to n' for penetrating X-radiation, each "infra-red term" diminishes approximately in the ratio n^2/n'^2 and each "ultra-violet term" (including the K, L, and M characteristic-radiation terms) in the ratio $-n_0^2/n'^2$. If n' be higher than the natural frequency of any of the constituent electrons all of the corresponding terms will become negative and therefore all the vibrating systems will affect the index of refraction in the same way. Assuming the general validity of this line of argument C. G. BARKLA deemed it worth while to subject the matter to careful experimental test.

The radiation from an X-ray bulb was sent through two narrow vertical slits in parallel lead screens which were about 50^{cms} apart. The rays finally fell upon a photographic plate at a distance of about 150^{cms} from the second screen. The image thus produced was a line 3^{cms} long and about 0.01^{cm} wide. Two crystals of potassium bromide, one above the other, were interposed in the path of the beam of X-rays at about 140^{cms} from the plate. The refracting edges of the prisms were parallel to each other and to the plane of the slits, but the so-called bases of the prisms were turned away from each other so as to lie on opposite sides of the beam of radiation. Consequently any refraction of the rays arising from transmission through the prisms would cause displacement in opposite directions of the upper and lower halves of the thin pencil of X-rays. An exposure of a fast plate was made for a period of about eight hours. It was found that the photographic impression was still an unbroken straight line. There was no evidence of the slightest relative displacement of the halves of the image. When looking along the line in a direction making a small angle with the plane of the plate it was estimated that a lateral shift of 0.025^{mm} could have been detected. From the fact that transmission through a prism did not produce a deviation as great as 2 seconds of arc, Barkla concludes that the

refractive index of potassium bromide for wave-lengths of the order 0.5×10^{-8} cm. is between 0.999,995 and 1.000,005.—*Phil. Mag.*, xxxi, p. 257, April, 1916.

H. S. U.

8. *Long-Range Alpha-Particles from Thorium*.—In the course of an examination of a strong source of the active deposit of thorium by the scintillation method, SIR ERNEST RUTHERFORD observed the presence of a small number of bright scintillations caused by particles which were able to penetrate through a thickness of matter corresponding to 11.3^{cms} of air at 76^{cms} pressure and 15° C. These scintillations were undoubtedly due to alpha-particles possessing a greater velocity than any previously observed; for, the swiftest alpha-particles hitherto known (namely, those from thorium C) have a range in air of 8.6^{cms} . The number of long-range particles decreased exponentially with the time, falling to half value in 10.6 hours—the normal period of decay of the active deposit of thorium.

The experimental part of the problem was taken up by A. B. WOOD and the following conclusions were derived from the observations. The atoms of thorium C can break up in three and probably four distinct ways with the emission of four characteristic groups of alpha-particles. The ranges of these particles in air at 15° C. are, for thorium C₁ 4.95^{cms} , for thorium C₂ 8.6^{cms} , for thorium C₃ (new) 10.2^{cms} , and for thorium C₄ (new) 11.3^{cms} . The respective velocities of the particles were found by calculation to be 1.71, 2.06, 2.18, and 2.26 times 10^9 cms. per sec. The swifter particles appear to be divided into two homogeneous groups amounting together to about 1/10,000 of the total number emitted by thorium C. Approximately two-thirds of the swifter particles have the range 11.3^{cms} .—*Phil. Mag.*, xxxi, p. 379, April, 1916.

H. S. U.

9. *The Science of Musical Sounds*; by DAYTON CLARENCE MILLER. Pp. viii, 286, with 187 figures. New York, 1916 (The Macmillan Co.).—This admirable book embodies the material presented in a series of eight lectures which were delivered by the author at the Lowell Institute in January and February, 1914. The titles of the lectures were: "I Sound Waves, Simple Harmonic Motion, Noise and Tone; II Characteristics of Tones; III Methods of Recording and Photographing Sound Waves; IV Analysis and Synthesis of Harmonic Curves; V Influence of Horn and Diaphragm on Sound Waves, Correcting and Interpreting Sound Analyses; VI Tone Qualities of Musical Instruments; VII Physical Characteristics of the Vowels; VIII Synthetic Vowels and Words, Relations of the Art and Science of Music."

Since the lectures were addressed to general but cultured audiences, a large part of the material was necessarily elementary and well known, and was selected and arranged to develop the principal line of thought. Consequently there is very little mathematical analysis in the text. Nevertheless, the later chapters involve the most recent progress of the science and give, first hand and in a very dignified, modest manner, a very clear account of the important investigations made in this field by the author.

Supplementary reading is facilitated by the appendix which contains ninety bibliographical references. Most of the illustrations are new, all of the diagrammatic figures are clear cut and illuminating, and the numerous half-tone reproductions of original photographs are excellent. Not only is the author's style unusually pleasing and logical, but his wide experience in research has enabled him to present the subject in a finished, masterly manner. Unquestionably the book constitutes a valuable contribution to the subject and it merits the attention not only of all students and teachers of physics, but also of those musicians who desire to acquire a full appreciation of the scientific foundation of their special art.

H. S. U.

10. *Theory of Errors and Least Squares*; by LEROY D. WELD. Pp. xii, 190. New York, 1916 (The Macmillan Co.).—In the preface the author says: "This small volume embodies the material used by the writer as lecture notes during the past twelve years. It is intended as a presentation of the Theory of Errors and Least Squares in such a simple and concise form as to be useful, not only as a text-book for undergraduates, but as a handy reference which any research worker can read through in an evening or so and then put into immediate practice."

In the very nature of the case, the ground covered does not afford anything especially novel, but, on the other hand, the manner of presentation seems to be unusually clear. This condition is largely brought about by the inclusion in the text of numerous practical illustrations taken from the fields of astronomy, chemistry, physics, surveying, etc. Scattered through the text and at the ends of the chapters 126 problems for solution by the reader may be found. The appendix contains supplementary notes on mathematical proofs and a collection of important definitions, theorems, rules and formulas for convenient reference. We heartily agree with the author's statement that "... for some reason, students are rarely given opportunity to acquire facility in these lines, the result being that too many of our scientists and engineers go about their work without such equipment," and hence we are glad to see that one possible cause for this condition—the non-existence of a short, practical text—has been completely removed by the present useful contribution.

H. S. U.

II. GEOLOGY AND MINERALOGY.

1. *The Strophomenidæ of the Kristiania region*; by OLAF HOLTEDAHL. Videnskaps. Skrifter, I. Mat.-Naturv. Klasse, 1915, No. 12, 1916, pp. 1-117, 16 pls., 7 text figs.—It is now more than twenty years since Hall and Clarke published their most excellent revision of Paleozoic Brachiopoda, and yet in all this time but very few Europeans have thought it worth while to revise their forms in the light of this far-reaching study. Buckman of England now has an associate in Hortedahl, and we hope the example set by these Old World pioneers in the study of

brachiopods along modern lines will be conducive to better paleontologic work in Europe.

Holtedahl here monographs all of the Ordovician and Silurian strophomenids found in southern Norway, 74 in number, of which 55 are named specifically. Of new species or varieties there are 22, and one new genus, *Palæostrophomena* (1 species). Of American genera there are *Rafinesquina* with 22 forms, *Brachyprion* 5, *Leptostrophia* 2, *Strophomena* 18, *Amphistrophia* 2, *Strophonella* 1, *Schuchertella* 1, *Leptæna* 5, *Plectambonites* 13, *Christiania* 1, *Triplecia* 2, and *Streptis* 1. We therefore learn that the generic development in America and Europe is almost identical, but in regard to the species the story is very different. There are only 8 forms that are certainly known to be common to the two continents (there may be 11), and of these 4 are ubiquitous (*Schuchertella pecten*, *Leptæna rhomboidalis*, *Plectambonites sericeus*, and *P. transversalis*). The first intercommunication of species, but to a very limited extent, occurs in the Middle Ordovician (Black River-Trenton), with a more liberal interchange in late Ordovician (Richmondian) and more especially in early Silurian time. In Europe the relationship in the earliest Ordovician is between Norway and western Russia, and then the exchanges in late Ordovician and Silurian times are between Great Britain and Norway.

The strophomenids of Norway and Russia begin in earliest Ordovician time in but few species, with small individuals. *Plectella* may be the progenitor of the family, and with it are soon associated *Rafinesquina*, *Palæostrophomena*, and possibly one or two other as yet undetermined genera. The first marked evolution takes place early in the Middle Ordovician with a more decided generic variation in latest Ordovician and earliest Silurian time.

Holtedahl has also grouped the species according to the kinds of rocks in which they occur, and we learn that the strophomenids in the main are lovers of clear seas depositing limestone. Of the common species, 36 are restricted to limestones, 3 to shales, and 12 occur in both habitats. The mud-lovers are usually the ubiquitous forms and the long-lived species are those that are adapted to varying habitats. Finally, there is on page 10 of the paper a valuable correlation table of the Ordovician and Silurian strata of Norway and western Russia. c. s.

2. *A revision of the Cheirurinae with notes on their Evolution*; by DONALD C. BARTON. Washington University Studies, Vol. III, Pt. I, No. 1, 1915, pp. 101-152, 25 text figs.—This valuable revision of cheirurid trilobites treats of 20 genera, of which 3 are new: *Pilekia*, *Kavina*, and *Lehua*. The subfamily may have had its origin in late Cambrian time, though none are known earlier than the Lower Ordovician. In the Middle Ordovician occurred the greatest amount of evolution, but four genera are known in the Silurian, and none appear to have endured into Middle Devonian time. The Cheirurinae are therefore essentially Ordovician animals. c. s.

3. *The Age of the Killarney Granite*; by W. H. COLLINS. Geol. Surv., Canada, Museum Bull. No. 22, 1916, 12 pp., 1 pl., 1 text fig.—This interesting pamphlet shows that the Huronian sediments on the north shore of Lake Huron, of more than 12,000 feet thickness, are intruded by sills and dikes of diabase that are probably of Keweenaw age. Near Thessalon they are overlain by a basic volcanic flow. Finally, and most important, they are also intruded by granite masses of a bathylithic nature that are of later pre-Cambrian age. These intrusions have folded and faulted the sedimentaries along the north shore of Lake Huron to a degree far more intense than elsewhere in Ontario. "The axis of folding crosses the district in a wide, southward curved arc." These bathylithic mountains of Proterozoic time were widely overflowed by the early Paleozoic seas and the region remained diastrophically neutral until Pleistocene time, when it was re-elevated to its present altitude. c. s.

4. *Morphology and Anthropology, a Handbook for Students*; by W. L. H. DUCKWORTH. Second edition, Volume I, pp. xvi, 304; 208 text figures. New York, 1915 (Cambridge Univ. Press; G. P. Putnam's Sons).—The second edition of this excellent handbook for students of the morphological aspects of anthropology has been entirely rewritten and is more abundantly illustrated than the first edition of 1904. It is a careful study of the general anatomy of the primates, the ancestors of man. About 50 pages are devoted to setting forth the classifications of the mammals, and 150 pages to the general anatomy of the primates. One chapter deals with the crania, another gives in much detail the dental system of the primates, the theories of cusp-development and the origin and fate of cusps. c. s.

5. *Geology and Geography of the Galena and Elizabeth Quadrangles*; by A. C. TROWBRIDGE and EUGENE W. SHAW. *History of development of Jo Daviess County*; by BERNARD H. SCHOCKEL. Illinois State Geol. Surv., Bull. 26, 1916, 233 pp., 25 pls., 50 text figs.—This interesting geologic, geographic and historic report is both scientific and educational. The formations at the surface in the areas described are of Ordovician and Silurian time. The bulletin contains other chapters on the work of the wind, ground waters and rivers, and the economic deposits. The last chapter deals with the settlement and development of Jo Daviess County. c. s.

Year-book for 1910. Administrative Report and various Economic and Geological Papers. Illinois State Geol. Surv., Bull. 20, 1915, 165 pp., 14 pls. (maps and sections), 8 text figs.—Besides the administrative and statistical reports this year-book contains the following papers: Carlyle oil field and the surrounding territory, by E. W. Shaw; Carlinville oil and gas field, by F. H. Kay; Geology and mineral resources of the Springfield quadrangle, by T. E. Savage; Extinct lakes in southern and western Illinois and adjacent states, by E. W. Shaw. c. s.

6. *Union of South Africa, Geological Survey*; H. KYNASTON, Director, Pretoria.—Sheets 12 and 13 of the geological map

have been issued, accompanied by descriptive pamphlets. The former sheet, described by W. A. HUMPHREY and H. KYNASTON, covers the geology of Pilandsberg and vicinity. A striking feature of this area is the Pilandsberg range, which is regarded as representing the most important focus of eruption of the elæolite-syenite magma in South Africa. The three types developed are (1) red syenite, (2) foyaite and lujaurite, and (3) nephelite-syenite. Sheet 13, described by A. L. HALL and H. KYNASTON, discusses the geology of the region of Haenertsburg, which is especially important for its productive gold fields.

Memoir No. 7 (Pretoria, 1916), by PERCY A. WAGNER, embraces the geology and mineral industry of the Southwest Africa region, which has changed its political allegiance within recent times. As is well known, the most important production of this country are the diamonds, which amounted in value to £3,500,000 in 1913, exceeding that of Southern Rhodesia for the same period. Since then the production has been reduced, because of over-production, but the territory ranks next to Griqualand West as the most important diamond-producing region in the world, having yielded from 1908 through 1913 over 20 per cent of the total world's production. The special diamond fields are near Lüderitz Bay but the detrital diamantiferous deposits extend along the coast for a distance of some 275 miles. There are also rich copper-lead deposits, developed particularly at Tsumeb and other localities. Further some forty large iron meteorites have been found thus far in Great Namaqualand, similarity in the composition of which leads to the opinion that they may all have resulted from a single meteoric shower. As regards the origin of the diamonds, although kimberlite occurs in the territory, it is considered more probable that the diamonds have been derived from a primary deposit submerged off the coast to the south of Pomona; no definite evidence is available in regard to the nature of this parent rock. Thus far the numerous pipes and dikes of kimberlite are barren of diamonds.

7. *New Zealand Geological Survey, Bulletin No. 17.* The Geology and Mineral Resources of the Buller-Mokihinui Sub-division, Westport division; by PERCY G. MORGAN and JOHN A. BARTRUM. Pp. viii, 210. Wellington, 1915.—The region described in the present bulletin lies in the central part of the west coast of the south island of New Zealand. It is especially important because of large deposits of high-grade bituminous coal which have been mined for many years. Brown coal and lignite also occur in quantity, and fifty years ago the production of gold from alluvial washings was very considerable. The total output from the bituminous coal mines, from 1877 to 1913, amounted to upwards of 12,000,000 tons. It is recognized, however, that the supplies of the bituminous coal are limited, and will approach exhaustion within 100 or, at most, 150 years. There is prospect, however, that brown coal and lignite may be added to the supply. There has been much question in regard to the age of the New Zealand coal-fields, but it is regarded as settled that the Brunner

and Kaiata beds are of Eocene age, but the Hawk's Crag breccia may be Cretaceous. This report covers, not only the discussion of the coal beds, but also the general and economic geology, physiography and finally the mineralogy.

8. *Geological Survey of Western Australia*; A. GIBB MAITLAND, Government Geologist.—Recent bulletins include the following:

No. 58, by R. ETHERIDGE, JR., describes Carboniferous fossils from localities in the valleys of the Minilya, Gascoyne, Wooramel and Irwin rivers. Eight plates give figures, in part of new species.

No. 62, by E. DE C. CLARKE, includes notes on the geology and mining at Sandstone and Hancock's of the East Murchison Goldfield. This region consists of a mass of quartz dolerite, highly altered, with dikes of granite and later of fine-grained basaltic dolerite; the dikes are believed to play an important part in connection with the deposition of gold, materially affecting the value of the ores. The rocks are described by R. A. FARQUHARSON.

No. 64. *Miscellaneous Reports, Series IV, Nos. 52-60.* Pp. 165; 17 pls. and 35 figs.—Nine papers on different subjects are included in this bulletin. Of these, one by the government geologist, A. GIBB MAITLAND, on the "Geology of Western Australia" is comprehensive in character and is accompanied by a sketch map in black and white. A second article by the same writer discusses the mining fields; of these the most important are those yielding gold, but there are also workable deposits of copper and tin. A single productive coalfield is mentioned, the Collie coalfield (also described in detail in this bulletin by H. P. WOODWARD); deposits of lignites and brown coal occur and may prove to be important in the future. E. S. SIMPSON describes the chloritoid of Yampi Sound with analyses.

No. 65, by H. D. WOODWARD, describes an area of 1,000 square miles in the Warren River District which came into prominence in 1902-4 in connection with oil speculation, and which has now been examined anew. Unfortunately the conclusion confirms that of earlier date, that it is unlikely to have any importance in the production of oil. The South coast asphaltum is described by E. S. Simpson. It is distributed in small quantities along the shore for a distance of 1,500 miles and is probably not of local origin, but rather brought in by the ocean drift from jettisoned or wrecked ship cargoes.

The Annual Progress Report of the Government Geologist for the year 1914 (41 pages with large map) gives an account of the work accomplished during the year in question.

9. *New Mineral Names*; by W. E. FORD (communicated).—The writer has been asked by the Editor of this Journal to prepare the following list of new mineral names. It is also planned to publish a similar list in the last numbers of the subsequent volumes. These lists will serve in a sense as continuous supplements to Dana's System of Mineralogy. The present list includes a number of names of minor importance which were overlooked in

the preparation of the Third Appendix to that work (1915) as well as those which have been proposed since the Appendix went to press. It is planned to make the descriptive matter given under each name as brief as possible, while still giving the important facts concerning the mineral.

The writer wishes to acknowledge the kind assistance of Dr. W. T. Schaller of the United States Geological Survey in the preparation of the following list.

Albanite. C. I. Istrati and M. A. Mihailescu, [Bul. Soc. Stiințe București, xx, 626, 1912]. Chem. Centralbl., i, 1587, 1912.—A black organic substance with a resinous luster. $G. = 1.644$. Fuses with intumescence between 85° and 110° . Burns with a sooty flame. Yields water at 110° and a large amount of gas between 195° and 305° ; above 305° a yellow liquid distills over. Found in Albania.

Alumogel. O. Pauls, Zs. prakt. Geol., xxi, 545, 1913.—Name suggested for the amorphous hydroxide of aluminium forming the main constituent of bauxite. Same as sporogelite, diasporogelite, etc.

Ambatoarinite. A. Lacroix, Bull. Soc. Min., xxxviii, 265, 1915.—A carbonate of strontium and the rare earths, probably $5\text{SrCO}_3 \cdot 4(\text{Ce, La, Di})_2(\text{CO}_3)_2 \cdot (\text{Ce, La, Di})_2\text{O}_3$. Orthorhombic? Occurs in crystals which are often arranged with parallel axes, forming skeleton-like groups. Prismatic angle about 95° . Optically negative. Acute bisectrix parallel to vertical axis. Axial plane parallel to (010). Refractive index greater than 1.658. Birefringence about 0.08. Occurs intimately associated with celestite, calcite, monazite, quartz, etc., at Ambatoarina, near Ambositra, Madagascar.

Arseno-bismite. A. H. Means, this Journal, xli, 127, 1916.—In cryptocrystalline aggregates. Color, yellowish green with tinge of brown. $G. = 5.70$. Refractive index about 1.60. Formula proposed as either $2\text{Bi}_2\text{O}_3 \cdot \text{As}_2\text{O}_5 \cdot 2\text{H}_2\text{O}$ or $4\text{Bi}_2\text{O}_3 \cdot 3\text{As}_2\text{O}_5 \cdot 5\text{H}_2\text{O}$. Occurs in impure condition with barite, limonite and small amounts of other minerals in the Mammoth mine, Tintic district, Utah.

Aurobismuthinite. G. A. Koenig, J. Ac. Sc., Philadelphia, xv, 405, 1912.—A sulphide of bismuth, gold and silver, $(\text{Bi, Au, Ag})_3\text{S}_2$. Granular, massive. Color, light gray. Soft. Unknown locality.

Bassetite. A. F. Hallimond, Min. Mag., xvii, 221, 1915.—From Basset group of mines, Cornwall, previously considered to be autunite. Monoclinic; $a : b : c = 0.3473 : 1 : 0.3456$; $\beta = 89^{\circ} 17'$. Twinned; tw. pl. $b(010)$, the a and c axes being interchanged. Cleavage parallel to $b(010)$, $a(100)$, $c(001)$. $G. = 3.10$. Color yellow. Transparent. Biaxial, negative. $2E = 110^{\circ}$. Ax. pl. within acute angle, β , inclined 4° to c axis. $\beta = 1.574$, $\gamma = 1.580$. Pleochroic, $\beta = \gamma$ deep yellow, α pale yellow. In the desiccator the extinction angle increases to about 20° . Comp.—Probably $\text{Ca}(\text{UO}_2)_2(\text{PO}_4)_2 \cdot 8\text{H}_2\text{O}$. Soluble in acids.

Belbaite. W. Vernadsky, Zs. Kr., liii, 283, 1913.—See under *Elbaite*.

Bilinite. J. Šebor, [Sborník Klubu přírodovědeckého, Prag, No. II, 2, 1913], N. Jb. Min., i, ref. 395, 1914.—Radiating fibrous. Color white to yellow. $H. = 2$. $G. = 1.875$. Optically resembles halotrichite. Comp.— $Fe''F'''_2(SO_4)_4 \cdot 24H_2O$ (an iron-halotrichite). Found in a lignite mine at Schwaz, near Bilin, Bohemia.

Bütschliite. R. Lang, N. Jb. Min., Beil.-Bd., xxxviii, 150, 1915.—Name proposed for the amorphous variety of calcium carbonate.

Chillagite.—A. T. Ullmann, J. Roy. Soc. N. S. W., xlv, 186, 1912; Smith and Cotton, *ibid.*, 207.—Tetragonal. $c = 1.5291$. Apparently hemimorphic. In tabular crystals, 1^{cm} by 2^{mm} . In cellular masses with crystals united or in nearly parallel growth. Common forms, $e(001)$, $y(119)$, $l(118)$, $p(111)$. Color straw- to citron-yellow, often brownish. Translucent. $H. = 3.5$. $G. = 7.5$. Brittle. Comp.— $3PbWO_4 \cdot PbMoO_4$. Occurs in a matrix of iron ochre with cerussite and wulfenite at the Christmas Gift-North mine at Chillagoe (whence name), Queensland.

Diasporogelite. F. Tucan, Centralbl. Min., 768, 1913.—More correct form of sporogelite.

Doelterite. A. Lacroix, Nouvelles Arch. Mus., v, 334, 1914.—It is proposed to call the titanium acids, $TiO_2 \cdot H_2O$ or $TiO_2 \cdot 2H_2O$, that are supposed to exist in the laterites of Guinea, by the name of *doelterites*, in honor of Prof. C. Doelter.

Dufreniberaunite. E. T. Wherry, Proc. U. S. Nat. Mus., xlvii, 509, 1914.—Name proposed for a hydrous, iron-manganese phosphate from Hellertown, Pa., intermediate in composition between dufrenite and beraunite.

Elbaite. W. Vernadsky, Zs. Kr., liii, 283, 1913.—In discussing the chemical composition of tourmaline, three molecules are suggested which by isomorphous mixtures might account for the variation in composition. These molecules are named *elbaite*, *belbaite* and *kalbaite*. The first occurs nearly pure in the pale red tourmaline from Elba, the last in the variety from De Kalb, N. Y.

Ferri-allophane. F. A. Nikolavskij, Bull. Ac. Sc. St. Pet., viii, 147, 1914.—Name given to an iron-bearing allophane from near Moscow, Russia.

Furnacite. A. Lacroix, Bull. Soc. Min., xxxviii, 198, 1915.—A basic chrom-arsenate of lead and copper. Found in small amount on a single specimen of diopside from Djoué, in French Equatorial Africa. Occurs in a mass of small prismatic crystals with acute angles and sharply-edged terminations. Apparently monoclinic. Color, dark olive-green. Color of powder, canary-yellow. High birefringence. Optically positive. Axial angle large. Dispersion strong. Fuses at high temperature with intumescence to a dark green glass with loss of water. Completely soluble in nitric acid. Gives reactions for arsenic, chromium, copper and lead. Name derived from *furnax* in honor of Lucien Fourneau, Governor of the French Congo.

Geraesite. O. C. Farrington, Geol. Soc. Am., Bull. xxiii, 728, 1912. A hydrous barium-aluminium phosphate, more acidic than gorceixite. From the favas of Brazil.

Grossouvreite. A. Lacroix, Min. de la France, v, 50, 1913.—A pulverulent opal from Vierzon, France.

Heliodor. O. Hauser and H. Herzfeld, Chem. Zeit., xxxviii, 694, 1914.—A name given to a yellow variety of beryl found in Southwest Africa and used as a gem stone.

Holmquistite. A. Osann, Sitzb. Ak. Heidelberg, 1913, 23, Abhlg.—A name given to a lithium-bearing glaucophane from the Island of Utö. Named in honor of Prof. F. T. Holmquist of Stockholm.

Kalbaite. W. Vernadsky, Zs. Kr., liii, 283, 1913.—See under *Elbaite*.

Kundaite. B. Doss, Centralbl. Min., 613, 1914.—Variety of grahamite from Kunda, Esthonia.

Lechateliérite. A. Lacroix, Bull. Soc. Min., xxxviii, 182, 1915.—Name given to the natural occurrences of fused quartz. Named in honor of Prof. Henri Le Chatelier.

Metatorbernite. A. F. Hallimond, Min. Mag., xvii, 333, 1916.—Synonym for metakupferuranite.

Minasite.—O. C. Farrington, Geol. Soc. Am., Bull. xxiii, 728, 1912.—A hydrous aluminium phosphate from the favas of Brazil.

Natromontebrazite. F. Gonnard, Bull. Soc. Min., xxxvi, 120, 1913.—Same as natramblygonite or fremontite.

Paredrite. O. C. Farrington, this Journal, xli, 355, 1916.—Name proposed for a "fava" from Minas Geraes, Brazil, which is composed of TiO_2 with a little water. Infus. but turns dark on heating. $G. = 3.97-4.08$. Name derived from *παρεδρος*, an associate.

Schernikite. D. S. Martin, Ann. N. Y. Ac. Sc., xxi, 189, 1912.—Name proposed for the fibrous prismatic pink variety of muscovite occurring at Haddam Neck, Conn. After Mr. Ernest Schernikow of New York City.

Stibiobismuthinite. G. A. Koenig, J. Ac. Sc., Philadelphia, xv, 405, 1912.—A sulphide of bismuth and antimony (Bi, Sb) $_2$ S $_7$. Contains 8.12 per cent of antimony. Large prismatic crystals. From Nacozari, Sonora, Mexico.

Thanite. M. Rozsa, Zs. Anorg. Chem., lxxxviii, 321, 1914.—Used as a name for a mixture of kainite and halite found in the Werra district, which has been formed from an original mixture of sylvite, kieserite and halite. Named after Prof. Karl v. Than.

Uranospathite. A. F. Hallimond, Min. Mag., xvii, 221, 1915.—Orthorhombic, pseudo-tetragonal. $a : b : c = 1.0 : 1.0 : ?$ In elongated tabular crystals. Twin-axis perpendicular to (110), in cruciform groups. Cleavage $c(001)$ perfect, $a(100)$ good, $b(010)$? fibrous. $G. = 2.50$. Color yellow to pale green. Biaxial, negative. Bx_{ac} perpendicular to $c(001)$. Ax. pl. parallel to elongation and to fibrous cleavage. $2V = 69^\circ$. $\gamma = 1.521, \beta = 1.510$. Pleochroic, $\beta = \gamma$ deep yellow, a pale yellow. Becomes uniaxial in the desiccator. Comp.—Hydrated uranyl phosphate. From

Redruth, Cornwall, previously considered to be autunite. Name derived from *uranium* and *σπάθη*, a broad blade.

Vegasite. A. Knopf, J. Wash. Ac. Sc., v, 497, 1915.—Hexagonal. In microscopic fibrous crystals, sometimes showing hexagonal plates. Optically —. $\omega = 1.755$, $\epsilon = 1.82$. Dichroic from brownish yellow to pale yellow, absorption $\epsilon > \omega$. A hydrous sulphate of lead and ferric iron. Analysis gives approximately following, $\text{PbO} \cdot 3\text{Fe}_2\text{O}_3 \cdot 3\text{SO}_3 \cdot 6\text{H}_2\text{O}$. Found at the Rosella prospect in the Yellow Pine district, Nevada. Name derived from Las Vegas, the chief town of the county in which the mineral is found.

Winchellite. D. S. Martin, Ann. N. Y. Ac. Sc., xxi, 189, 1912.—Name given to the nodular variety of mesolite from Grand Marais, Lake Superior. After Prof. N. H. Winchell.

Zinkdibraunite. K. Nenadkewitsch, [Trav. Mus. Geol. St. Pet., v, 37, 1911], Zs. Kr., liii, 609, 1914.—Name proposed for a zinc-manganese oxide, having the formula $\text{ZnO} \cdot 2\text{MnO}_2 \cdot 2\text{H}_2\text{O}$. Occurs in friable, earthy, chocolate colored masses with calamine ore from the Olkusz district, Russia. $G. = 4.63$.

New names arranged according to the chemical classification.

Sulphides	Phosphates, etc.
AUROBISMUTHINITE. $(\text{Bi}, \text{Au}, \text{Ag})_5\text{S}_6$.	Natromontebrazite. Same as fremonite.
STIBIOBISMUTHINITE. $(\text{Bi}, \text{Sb})_4\text{S}_7$.	DUFRENIBERAUNITE. Hydrous iron, manganese phosphate.
Oxides	MINASITE. Hydrous aluminium phosphate.
LECHATÉRIÈRE. Fused quartz.	GERAESITE. Hydrous barium, aluminium phosphate.
Grossouvreite. Var. of opal.	Metatorbernite. $\text{Cu}(\text{UO}_2)(\text{PO}_4)_2 \cdot 8\text{H}_2\text{O}$.
Alumogel. Diasporogelinite. Colloidal $\text{Al}_2\text{O}_3 \cdot \text{H}_2\text{O}$.	Same as metakupferuranite.
DOELTERITE. $\text{TiO}_2 \cdot \text{H}_2\text{O}$ or $\text{TiO}_2 \cdot 2\text{H}_2\text{O}$.	Bassetite. $\text{Ca}(\text{UO}_2)_2(\text{PO}_4)_2 \cdot 8\text{H}_2\text{O}$.
PAREDRITE. Hydrated TiO_2 .	Uranospathite. Hydrated uranyl phosphate.
ZINKDIBRAUNITE. $\text{ZnO} \cdot 2\text{MnO}_2 \cdot 2\text{H}_2\text{O}$.	Furnacite. A basic chrom-arsenate of lead and copper.
Carbonates	ARSENO-BISMITE. $2\text{Bi}_2\text{O}_3 \cdot \text{As}_2\text{O}_5 \cdot 2\text{H}_2\text{O}$.
BÜTSCHLIITE. CaCO_3 .	Sulphates
AMATOARINITE. $5\text{SrCO}_3 \cdot 4(\text{Ce}, \text{La}, \text{Di})_2(\text{CO}_3)_3 \cdot (\text{Ce}, \text{La}, \text{Di})_2\text{O}_3$.	Bilinite. $\text{Fe}''\text{Fe}'''_2(\text{SO}_4)_4 \cdot 24\text{H}_2\text{O}$.
Silicates	Thanite. A mixture of kainite and halite.
Holmquistite. A lithium glaucophane.	Vegasite. Hydrous sulphate of lead and ferric iron.
Heliodor. Var. of beryl.	Tungstate. Molybdate.
Belbaite, Elbaite, Kalbaite. Var. of tourmaline.	Chillagite. $3\text{PbWO}_4 \cdot \text{PbMoO}_4$.
Schernikite. Var. of muscovite.	Hydrocarbons
Winchellite. Var. of mesolite.	ALBANITE.
Ferri-allophane. Var. of allophane.	Kundaite. Var. of grahamite.

NOTE. Names printed in black faced type are of those minerals which because of their definite characters and the completeness of their description seem to warrant acceptance as definite species. Names printed in light-face capitals are of incompletely described minerals which at present are more or less doubtful in character. Variety names are printed in light-face lower case letters.

Mineralogical Laboratory of the
Sheffield Scientific School of Yale University,
New Haven, Conn., April 25th, 1916.

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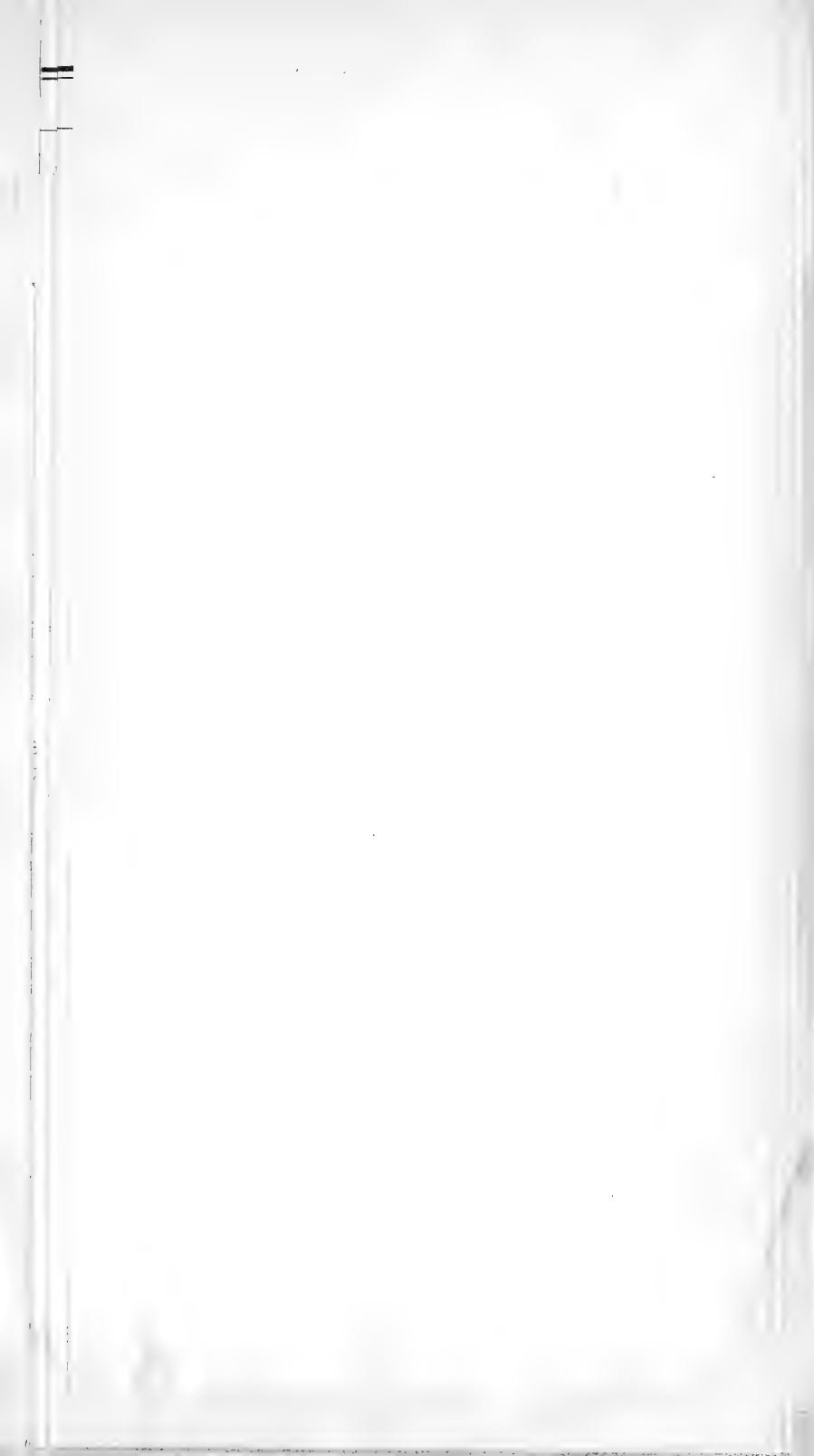
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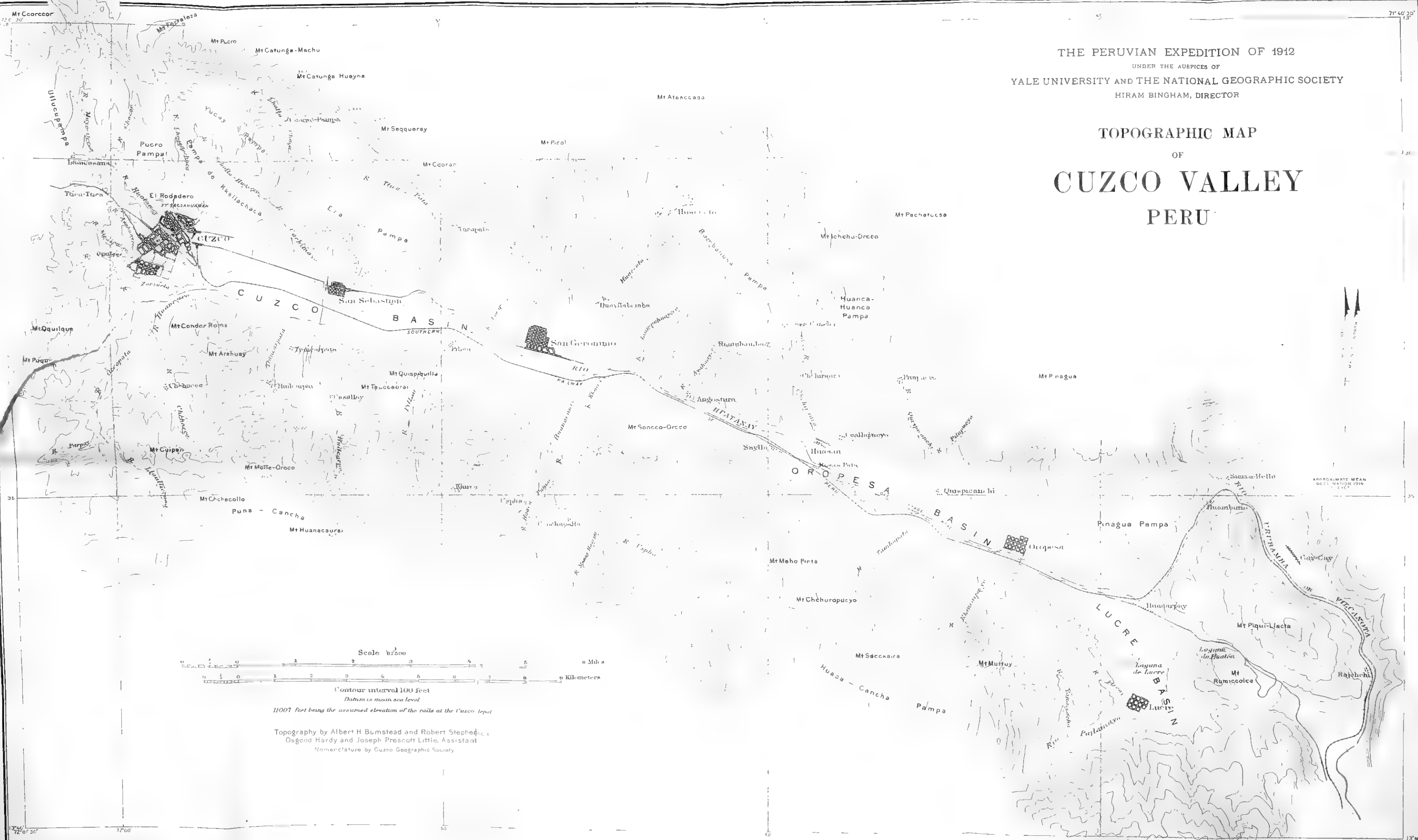
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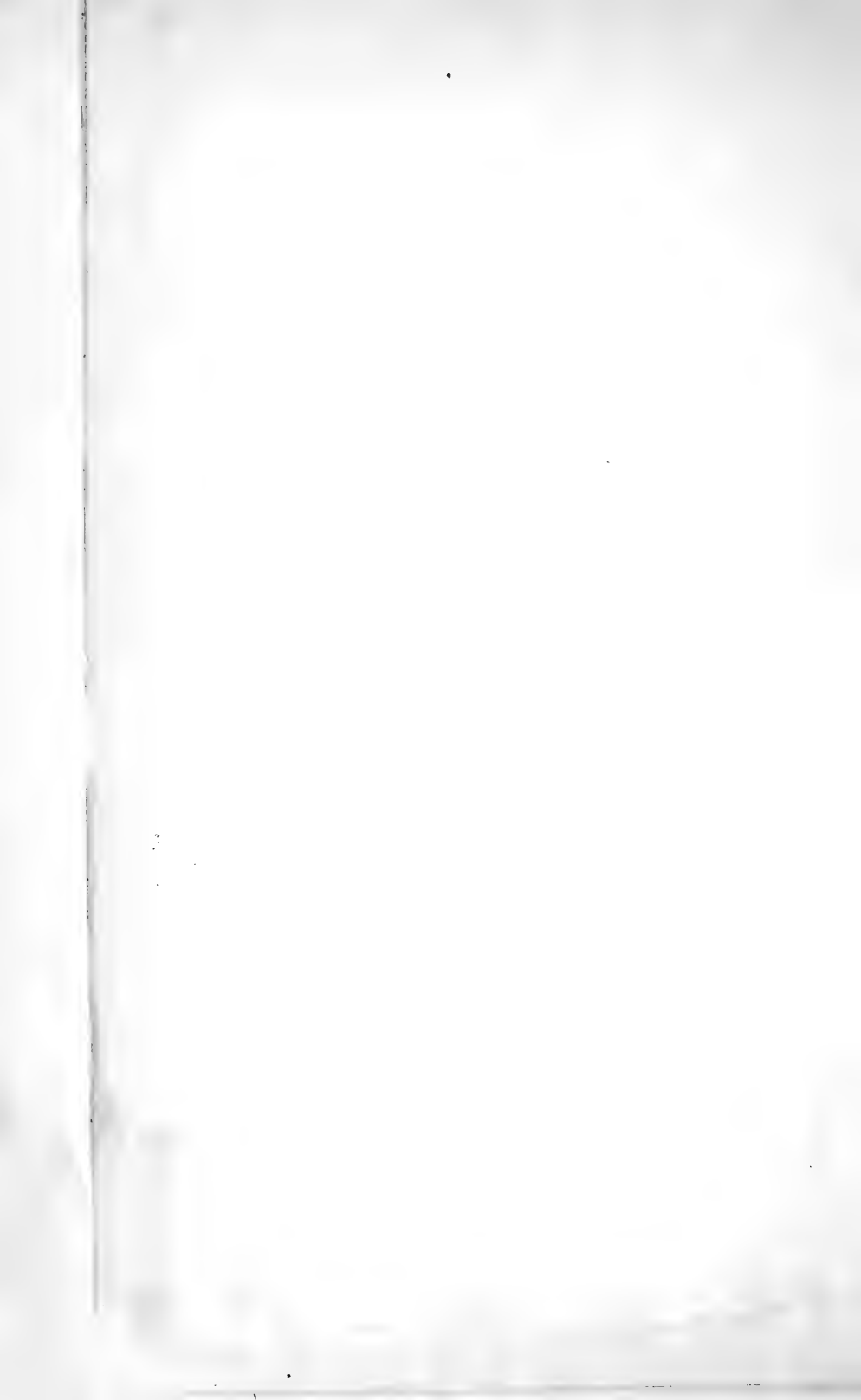
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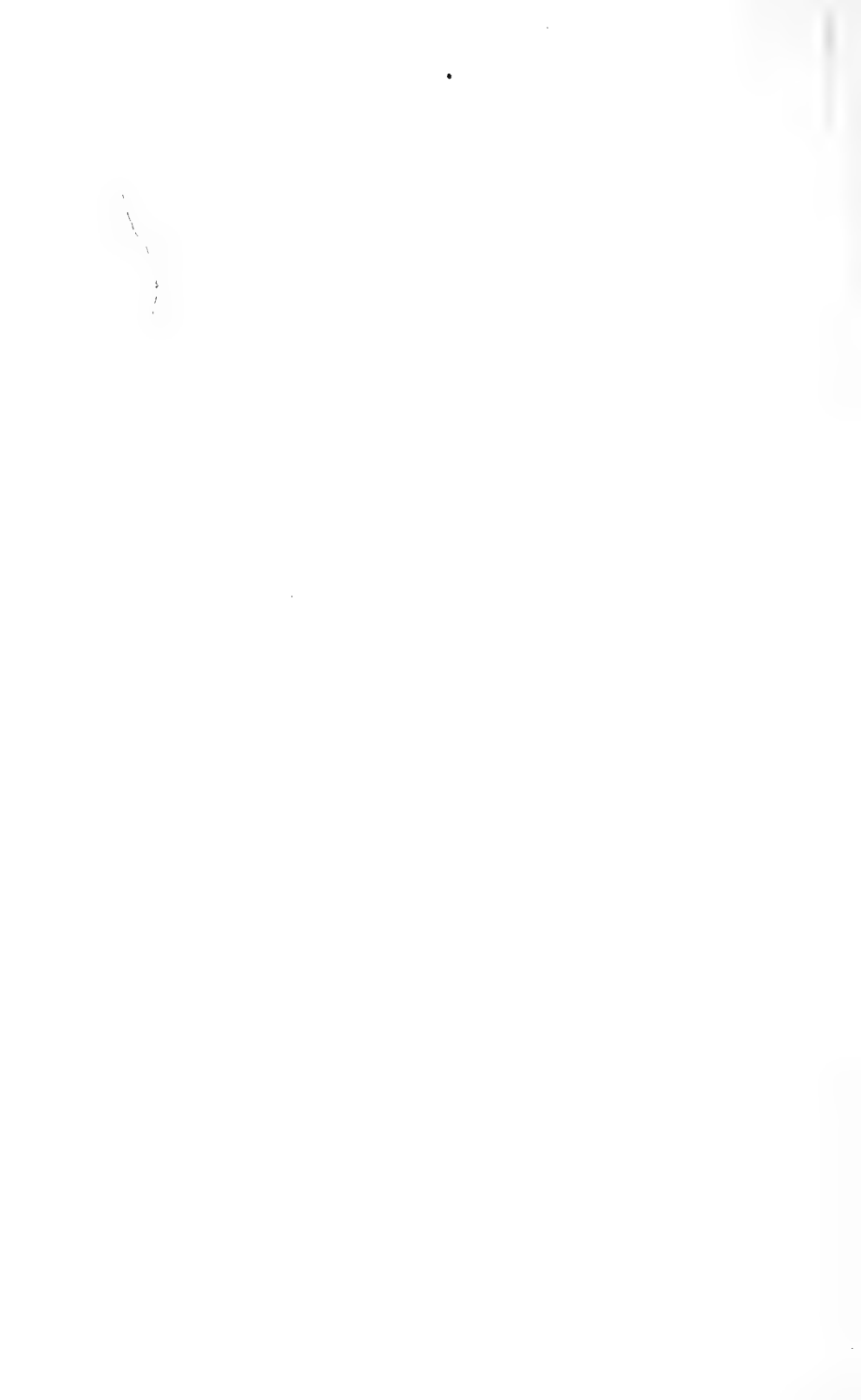


TOPOGRAPHIC MAP
OF
CUZCO VALLEY
PERU









THE PERUVIAN EXPEDITION OF 1912
UNDER THE AUSPICES OF
YALE UNIVERSITY AND THE NATIONAL GEOGRAPHIC SOCIETY
HIRAM BINGHAM, DIRECTOR

RECONNAISSANCE GEOLOGIC MAP OF CUZCO VALLEY PERU

LEGEND

SEDIMENTARY ROCKS

QUATERNARY

Glacial moraines

Glacial gravels

PLEISTOCENE

San Sebastian formation
(Laminar sands, tuffaceous silt, and adobe)

TERTIARY

Tb
Bambamarca formation
(White friable sandstone)

LOWER CRETACEOUS

Yucay formation
(Marine brecciated limestone)

JURA-TRIASSIC

Jh
Huancabamba formation
(Brown sandstone and argillaceous shales)

Jp
Molle-Orco conglomerate member
(Brown conglomerate and coarse sandstone)

Jp
Parhatuen formation
(Volcanic conglomerates and sandstone)

PERMIAN

Quilque formation
(Brown calcareous sandstone and greenish shales)

IGNEOUS ROCKS

TERTIARY

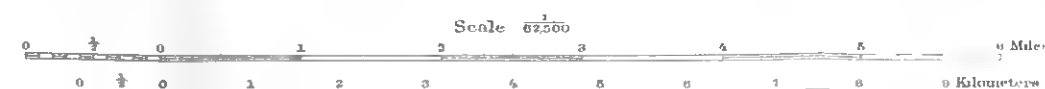
Lavas, andesites and basalts

Intrusives Diorite and Syenite

Faults

Strike and Dip

Strata Horizontal



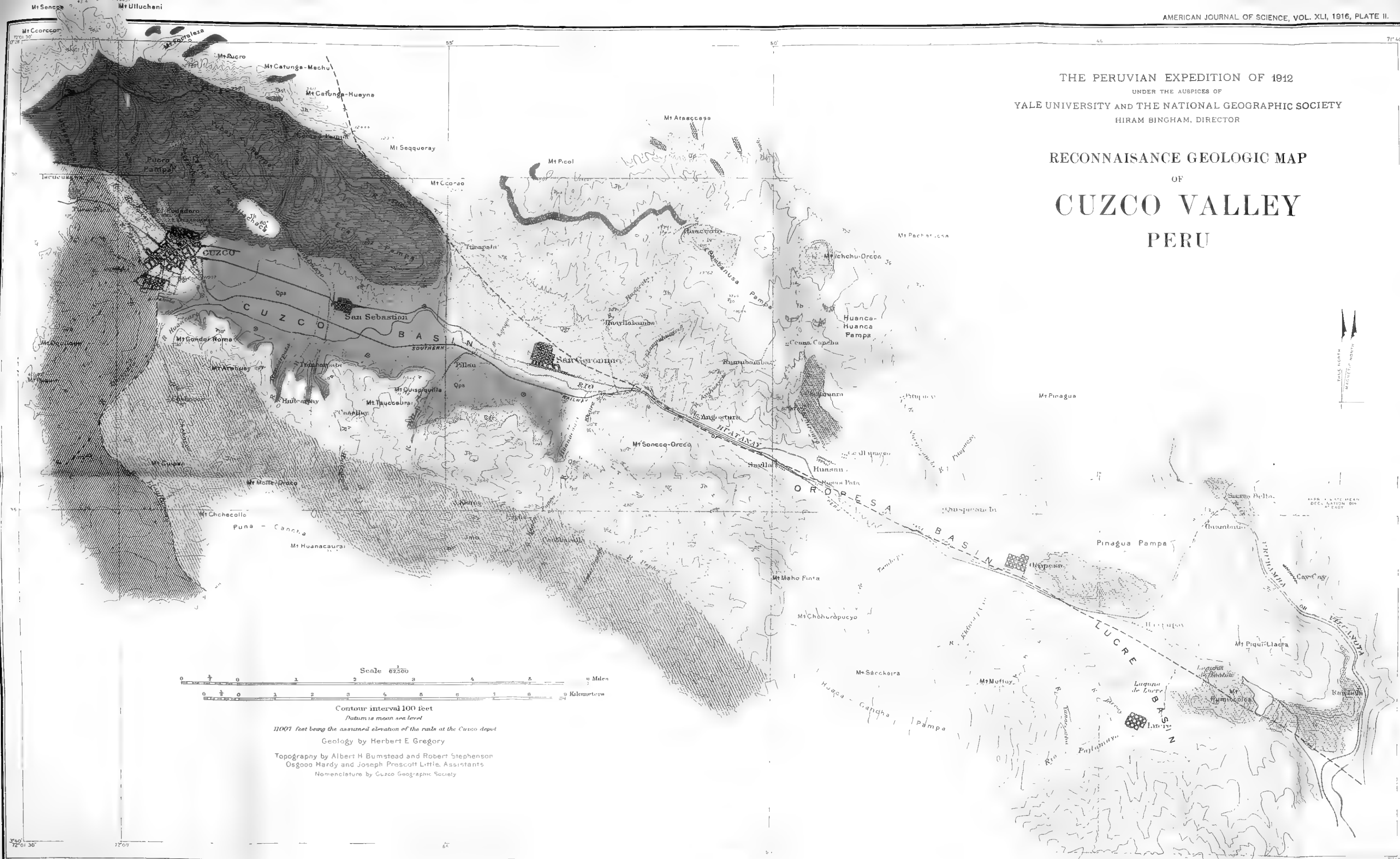
11001 feet being the assumed elevation of the rails at the Cuzco depot

Geology by Herbert E. Gregory

Topography by Albert H. Bumstead and Robert Stephenson

Osgood Hardy and Joseph Prescott Little, Assistants

Nomenclature by Cuzco Geographic Society





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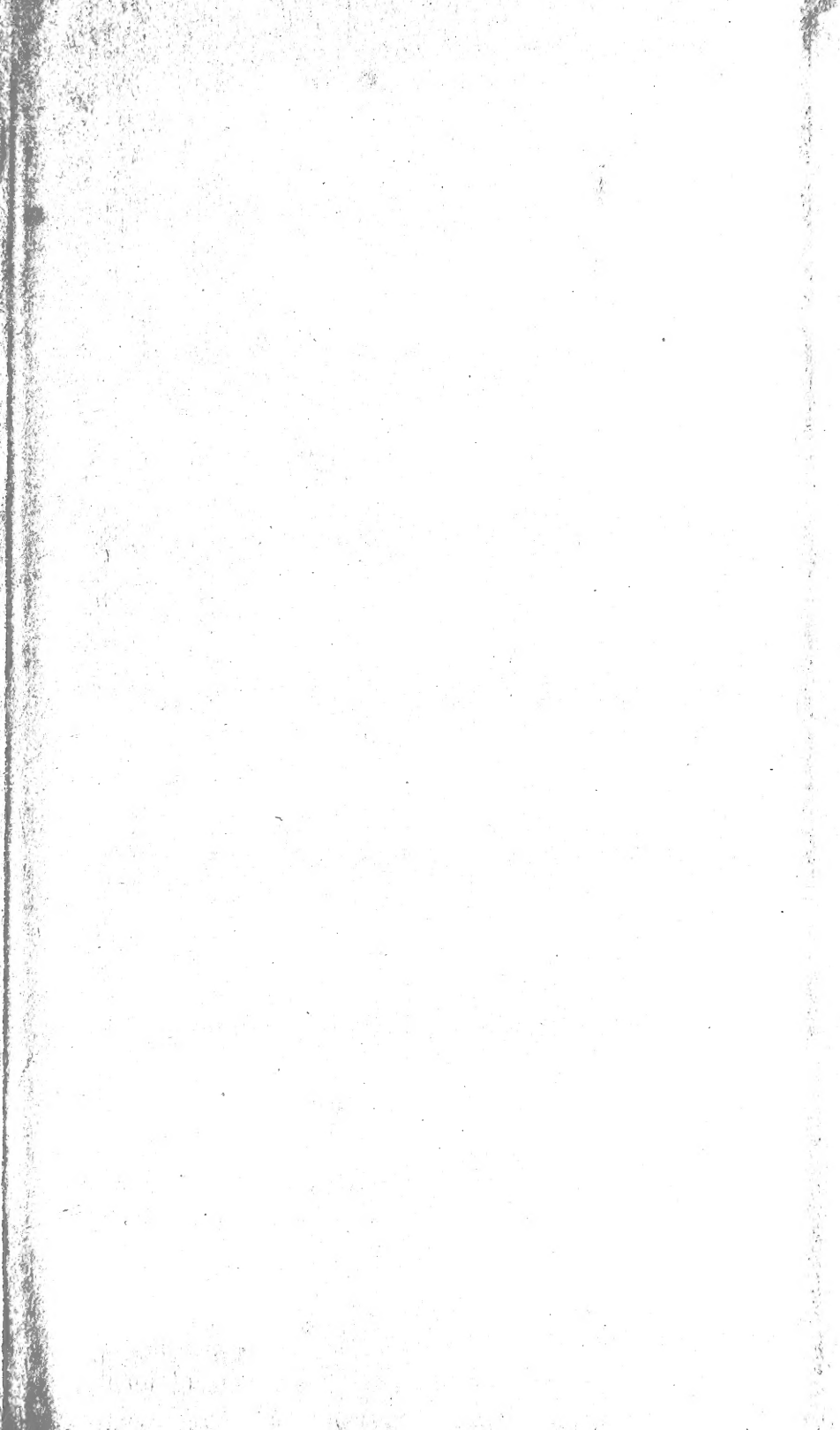
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